



Transportation economics and environmental issues that influence product strategy

Final report

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Executive summary

Chapter 1 - Introduction

TELCO (Tata Engineering Locomotive Company Limited) commissioned TERI (The Energy and Resources Institute), New Delhi to develop an objective and well researched policy document that projects vehicular growth in the context of current policies and emerging trends aimed at controlling vehicle emissions in India's urban transport sector.

This document is expected to help TATA Engineering assess and develop its research and product development strategy. The study particularly emphasized the following issues.

- 1 The growth potential of different categories of Indian vehicles over the next 20 years in India, in major states by analyzing the factors influencing the growth pattern.
- 2 Connections between emissions of criteria pollutants and their impact on health and health costs.
- 3 Current and emerging environmental regulations for motor vehicles in India and abroad.
- 4 Current and future fuel quality standards in Europe, the US, Japan and India, and international experience in the use of gaseous fuels (such as CNG and LPG) and bio-fuels (such as ethanol and bio-diesel) in motor vehicles.
- 5 An overview of the production and distribution infrastructure of liquid and gaseous fuels and factors affecting their pricing, based on the current taxation structure in India.
- 6 Status of current and future technologies in the world for vehicular emissions control for stoichiometric and lean burn combustion.
- 7 Developments in the area of electric, hybrid-electric and fuel cell vehicles in India and abroad.

No single study can provide a truly comprehensive treatment of transportation and environmental issues that influence a product development strategy. In conducting this study, TERI has made choices between breadth and depth of coverage to provide TATA Engineering with a feel of the critical issues that they need to consider in developing their road map.

Chapter 2 – Projections of vehicle numbers

This chapter aims to study the factors that influence the growth of vehicles and to project the vehicular population to 2020/21 in the states selected on the basis of high vehicular growth rates. The vehicle categories considered are (1) two-wheelers, (2) cars and jeeps, (3) three-wheelers, (4) taxis, (5) buses, (6) light commercial vehicles, and (7) trucks. The factors which influence vehicular growth included income level, level of urbanization, government policy, tastes, etc. Projections of growth in vehicle number have been made by establishing an econometric relationship with the most appropriate variable. Projections show that the average annual rate of growth for all categories will vary between 5% and 7% at the all-India level during a 20-year period from 2001 to 2021. However, the rate of growth projected varies widely across states for different categories of vehicles due to a number of factors such as level of urbanization, state size, road length, etc. which could not be analyzed due to paucity of data. The growth in number of vehicles in select cities was also looked at but projections were not possible because there were no data on factors influencing vehicular growth such as net domestic product (NDP), per capita NDP etc on a city basis. The projections made in this study represent broad trends; limitations arising from shortages in data and the impact of exogenous factors must be kept in mind. The chapter also looks at the impact of increasing share of public transport on the energy and environment outlook of certain cities based on available literature.

Chapter 3 – Air pollution and its health impact

The chapter reflects upon connections between pollutant emissions (with particular emphasis on regulated pollutants) and health and health costs, based on a literature review, with a focus on India.

Atmospheric pollutants commonly associated with motor vehicles, regulated through health-based permissible (progressively stringent) emission standards, include CO, HC, NO_x and PM. However, there is no direct relation between the growths in automobile number with the trends in ambient air quality of pollutants monitored by the Central Pollution Control Board. This suggests that other sources are responsible also and points to the need for studies on source apportionment. The available studies in Indian cities conducted between 1988 and 1995 reveal that the contribution of CO from motor vehicles is high (76%–90%), NO_x is moderately high (66%–74%) and while that of SO₂ is negligible. Particulate Matter is contributed by emissions from industrial processes, power gensets, burning of fossil fuels, resuspension of road dust,

natural dust, construction activities etc. The contribution of respirable particulate matter (RSPM) or PM_{10} — which is toxic and can penetrate deep into the respiratory tract — from motor vehicles running on different fuels is not known. In 2002, the National Environment Engineering Research Institute, Nagpur, conducted a source apportionment study of PM_{10} in Kanpur city. They estimated that around 16% of the PM_{10} originated from motor exhaust, 25%–40% from industrial and other sources, 33% from re-suspended dust and the earth's crust and a sizeable share from diesel generating sets.

Although vehicular pollution contributes significantly to the air pollution problem, no studies are available in the country that measure health costs on account of vehicle emissions alone. A World Bank study in India in 1995 has estimated the economic loss by environmental degradation in India, including cost due to air pollution in 36 cities in respect of PM, SO_2 , NO_x , and lead. The cost due to air pollution accounted for 14% of the total cost of environmental degradation that also covered damage from water pollution, hazardous waste of industrial origin, soil and rangeland degradation, deforestation, degradation of coastal and marine resources, loss of biodiversity, and decline in tourism. The study concluded that the annual health costs due to ambient air pollution levels ranged between 517 million dollars and 2,102 million dollars (or 25 billion rupees to 100 billion rupees). It also estimated that over 40,000 premature deaths would be avoided if pollutant levels in these cities were reduced to the WHO annual average standard. Another study by TERI in 1998, which considered more sources of pollution and the entire country (including rural areas), estimated the annual loss in the range of 885 billion rupees to 4,250 billion rupees. The TERI study revealed that of a total of 8.2 million deaths in India, in 1989, anywhere between 0.9 and 3.6 million could be attributed to particulate air pollution.

Indian cities are characterized by high levels of PM and NO_x , with PM being the greatest cause for concern. The annual average ambient concentration levels of PM exceed national ambient air quality standards at a number of monitoring sites in the country. The 1990 World Health Organization guidelines states the current time series epidemiological studies are unable to define a threshold below which no effects occur. Recent studies suggest that even at low levels of PM (less than $100 \mu g/m^3$), short-term exposure is associated with health effects.

While the environmental impact of PM and NO_x emissions from diesel engines is greater than that of the emissions from petrol, CNG and LPG engines of similar size, the emissions of CO and HC are higher from petrol, CNG and LPG compared to those from a diesel engine. All over the world, vehicle

emission control directives focus on improved engines and better fuel quality, and also the introduction of emission control devices such as catalytic converters, oxidation catalysts, particle filters, etc. Measures such as better maintenance of vehicles in use, phasing out old vehicles, would play a vital role in reducing emissions from the transportation sector.

Chapter 4 – Environmental regulations for motor vehicles

This chapter provides an overview of environmental regulations for motor vehicles in India, the European Union, the United States, and Japan. It also presents the road map drawn up for the automobile industry, and oil and gas companies for achieving more stringent tailpipe emissions from motor vehicles in different regions of the world.

Technologies to reduce emissions from spark-ignition (petrol powered) engines were first introduced in the United States and Japan in the late 1960s. Europe followed with similar regulations a decade later. Standards for exhaust emissions of CO, HC, NO_x and PM, and for evaporative emissions of volatile organic compounds (such as benzene, butadiene, formaldehyde, and acetaldehyde) from vehicle fuel systems, have become progressively more stringent with the trend expected to continue. Emissions from new vehicles in the most strictly controlled regions are over 90% lower than they were prior to control. Other countries, including India, are following this step-by-step regulatory approach, albeit with some lag.

The regulatory approach for emissions control from vehicles powered by compression-ignition (diesel) engines is also following a similar trend. The emission levels of PM and NO_x emissions from uncontrolled compression-ignition engines are higher compared to those for emissions from spark-ignition engines equipped with catalysts. This is because exhaust treatment or emission control technologies – catalysts for NO_x, traps for particulates – were not sufficiently developed to enable their widespread use. Both technologies are marking progress now and a detailed review of their current status is presented in Chapter 7. Plans are in place to reduce NO_x and PM emissions significantly from current levels (which are about a factor of three below uncontrolled levels).

In India, tailpipe emission regulations for new vehicles were first notified on 5 February 1990 and became effective on 1 April 1991. These were then revised and made more stringent in April 1996. Emission norms for 2000 were also announced. The general consensus is to use the European standards but emission norms lag behind Europe's by four or five years for all vehicle categories except two-and three-wheelers. For these, India 2000 norms are far

stricter than Euro II norms and are some of the world's most stringent. These norms have been implemented throughout the country since April 2000.

Euro I norms were brought into force throughout the country with effect from 4 January 2000 for all vehicle categories. However, Bharat Stage II norms (equivalent to Euro II) were brought into force only in the NCT, Delhi, with effect from 4 January 2000 and extended to the city of Mumbai with effect from 1 January 2001. Catalytic converters have been made mandatory for all four-wheeled petrol driven vehicles registered in the four metro cities and 45 other cities in the country. From April 1995, along with the supply of unleaded petrol, mandatory fitment of catalytic converters in new petrol passenger cars sold in the four metros of Delhi, Kolkata, Mumbai and Chennai was effected.

The initiatives for improving fuel quality in the country were taken by the Supreme Court. Although it is expected that petrol and diesel will continue to be the predominant fuel for many years, alternative fuels such as CNG and LPG are also being envisaged. Still other alternatives such as di-methyl ether, bio-diesel, and ethanol-blended petrol are at different stages of experimentation.

The chapter also summarizes the recommendations made by the following committees. (1) The Environment Pollution (Prevention and Control) Authority (EPCA). (2) The VM Lal Committee. (3) The Mashelkar Committee.

Chapter 5 – Fuel quality and alternative fuels

The chapter examines current policies for developing and promoting the use of cleaner conventional liquid fuels (diesel and petrol), gaseous fuels (CNG and LPG), and bio-fuels (ethanol and bio diesel) in the transport sector in India, the European Union, and the United States.

Conventional fuels

The two auto liquid fuels (diesel and petrol) of specified quality will remain the main auto fuels throughout the country. All over the world, initiatives have been taken to improve the quality of diesel and petrol through the removal or/reduction of fuel constituents such as sulphur and polynuclear aromatic hydrocarbons in diesel, and sulphur, lead, benzene and other aromatics in petrol.

In India, the Fuels Sub-Committee of the Bureau of Indian Standards (BIS) has laid down the specifications for fuel quality based on emission norms. Refineries in the country are now producing unleaded petrol and fuels with a lower sulphur content that enable advanced emissions technologies to be used in vehicles. Benzene levels in petrol have been capped at no more than 1% in Delhi

and Mumbai to begin with. Besides improving fuel quality, oil marketing companies are adding performance-improving additives to both petrol and diesel.

Diesel

Probably the most important characteristic of diesel fuel is its sulphur content – increased sulphur content results in higher levels of sulphur dioxide (SO₂) and exhaust particulates, 10%–15% of which contain sulphates. Fuel desulphurization is the only technique currently available to reduce sulphur emissions. The aromatic content of diesel fuel is also important as an increase in aromatics increases particulate, HC, and NO_x emissions. Another important characteristic is the ignition quality which is characterized by the cetane number. Other fuel considerations for diesel engines centre around fuel purity and its relationship to diesel particulate control. Fuel additives may also be important with respect to diesel particulate control.

Even the diesel with 500 ppm sulphur that is supplied in the four metros has higher PM emissions leading to the search for gaseous fuels such as CNG and LPG. However, ultra-low sulphur diesel (ULSD) with a very low sulphur content (maximum 0.005% sulphur m/m or 50 ppm sulphur content) used with appropriate after-treatment (emission control) devices is as clean as gaseous fuels with respect to PM emissions.

Many European countries, particularly those in northern and western Europe, are already committed to ULSD. ULSD is known as city diesel in Europe and was introduced in Finland and Sweden in 1993; since then it has captured 100% of the Scandinavian diesel markets. ULSD is now available in Europe from several suppliers, including Shell, BP, Total, Neste, and Greenergy, and the fuel is also available in Hong Kong. ULSD is commercially available in the USA but in limited areas, mostly in California and the northeastern states of Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, and Maryland. Texas and the midwestern states (Ohio, Indiana, and Illinois) will now also have ULSD supplied by British Petroleum.

Petrol

Adding lead is the cheapest way of improving the octane level of petrol. With the phasing out of lead from petrol from the country, the improved octane number is now achieved by increasing the severity of refining processing but this entails additional energy consumption, increased refining costs, and less petrol per barrel of crude oil. Some of the increased costs associated with reduction or

elimination of lead in petrol can be lowered by blending petrol with high octane oxygenated supplements. The commonly used oxygenates internationally in petrol blends are methanol, ethanol, isopropanol, methyl tertiary butyl ether (MTBE), tertiary butyl alcohol (TBA), and iso-butyl alcohol. The volume of oxygenates in petrol blends varies from 3% – 10%. The oxygen content of the blend is generally 1% – 2% by weight. Oxygenates serve three basic objectives: extending the petrol stock or serving as a fuel substitute (gasohol, 5% ethanol blended with petrol in India), boosting octane value for a better anti-knock performance, and providing an effective means of reducing harmful emissions. Efforts are also being made to reduce the aromatic, olefins, and sulphur content of the fuel.

Gaseous fuels

In recent years CNG and LPG have gained considerable importance as gaseous auto fuels in a number of cities as they emit less particulates as compared to the present quality of diesel available. However, CO and total HC emissions are significantly higher in gas powered uncontrolled engines. CNG and LPG are best suited for spark ignition engines and have emerged as a viable alternative for petrol-driven vehicles. The introduction of emission control devices will enable vehicles running on gaseous fuels to emit lower levels of CO, HC, NO_x and toxic pollutants. Major oil companies are currently focussing on auto LPG, so the number of LPG vehicles is likely to grow faster than those on CNG until refineries start producing conventional fuels of Euro III and Euro IV quality. However, it should be noted that the use of gaseous fuels has certain safety and performance implications that need to be carefully evaluated. Clear standards for environmental performance of gaseous fuels should be set when they are first introduced.

Bio-fuels

Bio-fuels have gained national attention because of their potential to reduce reliance on imported energy and promote the domestic renewable energy programme. The two bio-fuels, gasohol and bio diesel, have a promising future.

Recent announcements by the government have mandated blending of ethanol upto 5% in nine states (Andhra Pradesh, Karnataka, Maharashtra, Tamilnadu, Punjab, Haryana, Uttar Pradesh, Gujarat, Goa) from 1 January 2003 which will later on be mandated for the entire country. It would be important to analyze the economic impact of such decisions and address technical issues. Ethanol blends have a higher Reid Vapour Pressure (RVP) when blended with

petrol lowering which would mean additional costs to the refinery. The volatility of gasohol would effect evaporative emissions and engine performance and therefore need to be studied. Corrosion of automobile parts when gasohol is used is another concern.

Bio-diesel is an esterified oil produced from edible or non-edible oil sources. Different countries use different base oils for producing bio-diesel which results in the fuel properties varying slightly, although the cetane number is similar to that of conventional diesel. This enables the use of bio-diesel with little or no modification to current diesel engines. Besides zero sulphur diesel enables the use of all advanced after-treatment devices to bring down significant emissions. In India, the development of bio-diesel is relatively young and some pilot studies are being carried out on some trans-esterified oils from seeds. A major issue concerning bio-diesel is its cost which has not been studied.

The introduction of alternative fuels (gaseous or bio-fuels) requires changes in the distribution, marketing and end-use systems. Irrespective of economics, an inadequate supply of fuel or unreliable distribution systems could adversely affect consumer acceptance of alternative transportation fuels. Experience with the use of ethanol in Brazil and CNG in New Zealand and elsewhere suggests that the main factors influencing large-scale introduction of CNG and alcohol fuels are price competitiveness, availability, and cost of feedstock (e.g., sugarcane for ethanol, or natural gas for CNG), fuel safety and quality standards, a reliable system of distribution, and the technical quality of vehicles (driveability, durability, safety).

Chapter 6 - Infrastructure and pricing issues related to fuels

The chapter provides an overview of the production and distribution infrastructure of liquid and gaseous fuels and factors affecting their pricing, based on the current taxation structure.

Liquid fuels

The Mashelkar Committee has recommended a roadmap for vehicular emission norms for auto vehicles where the entire country will move gradually from Bharat Stage II to Euro III and finally to Euro IV in 11 identified cities by the year 2010. The Committee has also identified refineries which could upgrade their facilities to produce these fuels at a relatively lower cost compared to other refineries because of their level of technical sophistication.

It is TERI's view that these refineries should be directly upgraded to produce Euro IV fuels by 2006/07 instead of a phased introduction to Euro III

and then to Euro IV by 2010 for reasons of cost effectiveness and export competitiveness. Also the earlier phasing in of Euro IV fuel quality would yield significant benefits even with current vehicular technology.

Oil companies have an extensive network of retail outlets in the country totalling over 19,000 retail outlets. Upgrading the quality of a fuel will not require any addition or change in the infrastructure.

It is the government's intention to leave market forces to determine the prices of petroleum products. However, this is likely to happen only when an independent regulator is appointed and the government dissociates itself from the pricing process.

It is unlikely that the duty element on petrol will be reduced, and the differential between petrol and other products will continue. However, a move has been made to reduce the subsidy on LPG and kerosene. As provided in Budget 2003, the excise duty on gasohol is lower by 75 paise per litre compared to petrol. This incentive, ethanol producers say, is not enough.

Gaseous fuels

The Mashelkar Committee recognizes the fact that CNG as an alternative fuel is possible only in cities fed by natural gas pipelines and with the infrastructure for distribution. It has also pointed out that limited domestic availability of LPG means a dependence on imports, which would imply higher costs for import terminals and inland infrastructure.

CNG

Despite the recent find by Reliance Industries of 196 BCM of substantial reserves of gas in the Krishna Godavari (KG) basin, capable of sustaining a supply of 14 BCM annually, domestic supply is unlikely to keep pace with demand. To meet the current and future shortfall there are plans to import gas by pipelines from neighbouring countries such as Bangladesh, Iran etc., and liquefied natural gas (LNG) from the Middle East, etc. The second option is the more likely as it does not involve any geo-political issues.

GAIL plans to expand the capacity of the HBJ pipeline from the current levels of 33.4 MMSCMD to 60 MMSCMD to cater to the increased availability of gas from LNG plants in Gujarat. If gas supply from Bangladesh fructifies, this could be fed into the northern region by a pipeline traversing West Bengal, Bihar, and UP. The Reliance gas find in the KG basin could see the start of a southern gas network and the makings of a national grid.

It would not be economical to lay long distance transmission lines only to meet CNG demand in the transport sector. Therefore, the growth of a CNG network will depend on the growth of the transmission network for the power fertilizer and industry sectors. Supplying CNG to the transport sector would also require additional gas compressor stations and dedicated CNG outlets.

Domestic gas is currently capped at 2850 rupees/MCM (1.71 dollars/MMBtu) at the supply source or 2.45 dollar/MMBtu in Delhi which is approximately 50% of fuel oil parity. If domestic prices are not raised, in order that users of regasified LNG are not discriminated against, it may become necessary to introduce a pooled gas price.

LPG

Unlike CNG, India has a well diversified network of domestic LPG sources and a total of 203 LPG bottling plants (each with its own bulk storage facility). To meet the shortfall between supply and demand, there are import terminals at Mumbai, Vishakapatnam, Mangalore and at Kandla which is connected by pipeline to Loni in UP.

The major advantage that auto LPG currently has over petrol is the lower level of taxes. In addition, LPG storage and dispensing units can be installed at existing retail outlets.

Chapter 7 – Emission control devices

The chapter reviews technologies for post combustion emission control and the role of fuel quality in reducing the levels of pollutants. The chapter is divided into two parts. The first part presents an overview of the catalyst technology for emission control commercially available. The second part deals with emerging new technologies for emissions control for stoichiometric and lean burn combustion.

Tighter emission standards have required more specific attention to the treatment of vehicle exhaust emissions. Commonly used technologies to control exhaust emissions include recirculation of exhaust gases, electronic control of engine performance, exhaust after-treatment or emission control devices (such as oxidation catalysts, particulate filters, continuously regenerating particulate traps etc.), and advanced combustion techniques, in combination with good quality fuels (such as unleaded petrol, low sulphur petrol, diesel). Enhanced engine management reduces emissions to very low levels. Each emission control device, including DeNO_x catalysts and NO_x traps, is described in detail.

The majority of car manufacturers in India has foreign collaborations for new technologies. This is, however, not true for heavy vehicles, buses trucks, two- and three-wheeled vehicles. Retrofitting emission control devices can help in reducing emissions from in-use vehicles as well. Not much work has been done in India in this area and it needs to be taken up with the help of R&D institutions and testing agencies.

Chapter 8 – Alternate power packs

Stringent environmental regulations and efficiency requirements are creating niche markets for alternate vehicle technologies. Some of these receiving global attentions are: electric vehicles, hybrid vehicles, and fuel cell vehicles. The electric vehicle and hydrogen-fuelled fuel cell vehicle use an onboard electricity source (battery or fuel cell) for traction with zero local emissions. Hybrid electric vehicles combine the existing internal combustion engine with onboard batteries for a fuel efficient and low emission traction system. The present share of such is minimal though the popularity of hybrid electric vehicles seems to be growing.

Several international and Indian automotive manufacturers have launched electric vehicles including buses, cars and three-wheelers but there are problems related to the driving range, recharging time, battery weight and life, as well as battery recharging facilities. Governments are providing incentives for promoting electric vehicles both, for public and private usage. Regulations are also being enforced to allow only zero emission vehicles such as electric vehicles in areas of strategic importance.

Hybrid vehicle technology is being seen as a near-term solution to reducing emissions while maintaining driving comforts. The ability to use the present hydrocarbon infrastructure and to provide a longer driving range has ensured a growth in sales of hybrid electric vehicles over the last six years in the developed countries. At present, Toyota and Honda have launched commercial versions of their hybrid electric cars. In India hybrid electric buses and three-wheeler prototypes have been developed with a view to deploying these vehicles for urban transportation in cities where gaseous fuels (CNG and LPG) are not available.

Fuel cell vehicles have been receiving attention worldwide as long-term an alternative traction systems. Hydrogen is being promoted as the onboard fuel for fuel cell vehicles. International automotive manufactures have ongoing programme to develop fuel cell vehicles in association with fuel suppliers. Automotive manufactures have built and demonstrated different prototype versions of fuel cell buses and cars. The deployment of fuel cell vehicles on a

commercial scale will have to evolve in parallel with a hydrogen supply and refuelling infrastructure.

Emerging scenario

This report discusses critical developments in the automobile industry, the oil and gas sectors, air pollution and its health impact, technological advances relating to emission control, judicial decisions and policy measures to contain vehicular emissions, projected growth in vehicular population in the context of increasing urbanization and economic growth. These developments throw up different possibilities. It is clearly not possible for any study to predict what precisely will happen in each of the areas even over the next five years; what can, at best, be done is to make some assessment of the scenario that is most likely to emerge. That scenario is likely to be the following:

- The Mashelkar Committee Report is likely to be accepted by the government shortly. Environmental groups are, however, likely to urge that the schedule recommended by the Mashelkar Committee for introducing Euro III norms by 2010 and Euro IV norms in the metros by 2010 be advanced; the Mashelkar Committee has not even set a time frame for introducing Euro IV norms in the whole country. In fact, TERI itself has been arguing that it should be possible to implement Euro IV norms in all the metros by 2005, and in the whole country by 2007/08. It is likely that the Supreme Court, which has already taken cognisance of the Mashelkar Committee Report, will direct that the deadline for the implementation of Euro IV norms in the whole country be set for 2007/08.
- Activism by the Supreme Court and some high courts to curb vehicular pollution is expected to continue. The Supreme Court has already directed that priority should be given to the transport sector in regard to the allocation of CNG in Delhi and other polluted cities in India. It is likely that the Mumbai High Court will also direct that CNG be made available for public transport at least in Mumbai. It is understood that GAIL is proposing to introduce CNG in Kolkata as well.
- LPG is likely to emerge as an alternative clean fuel in the metros and the more polluted cities since the investment on infrastructure required will not be significant.

- Even with the discovery of natural gas in the Krishna-Godavari basin, it is likely to be in short supply. The gap will probably be filled by the import of LNG as the import of natural gas through pipelines is beset with geo-political problems.
- Once the Mashelkar Committee's Report is accepted by government, it would become mandatory for the refineries to supply Euro III and Euro IV fuels according to the time frame set by government. This process can surely be expedited if the government decides to provide fiscal incentives to the refineries. Even otherwise, the refineries would have to start progressively producing ULSD as they would find it difficult to export diesel when refineries in Singapore and in middle east commence producing ULSD around 2006/07. Competitive pressures will advance the availability of ULSD in India and these pressures will be further strengthened by the Export-import policy, 2003, which permits oil marketing companies to import petroleum products to meet the demand.
- Experiments carried out in New York, London etc. have established beyond doubt that ULSD with appropriate emission control devices in heavy duty vehicles is as clean a fuel as CNG. These are collaborated by the preliminary findings of the TERI-ARAI evaluation of emissions from buses running on CNG and ULSD in Mumbai. ULSD is likely to be used in captive fleets for public transportation such as the BrihanMumbai Electric Supply and Transport Undertaking, Bangalore Metropolitan Transport Corporation, Calcutta State Transport Corporation etc. as an alternative to CNG over the next few years. Even in cities where CNG is available, the public transport market is likely to be divided between CNG and ULSD.
- With competition in the market, oil companies are becoming increasingly conscious of the need to address issues of fuel adulteration and ensure product quality. The automobile industry can now plan technology advances accordingly.
- Increasing competition in the automobile sector together with an increasing quality consciousness has in the part of consumers will result in advanced technologies being introduced at competitive prices. This could result in:
 - Four-stroke engines replacing two-stroke engines in two- and three-wheelers.

- Turbo-charged intercooler diesel cars being introduced together with appropriate emission control devices, resulting in an increase in the share of diesel cars as in Europe.
- Buses specifically designed for urban transport replacing buses built on a truck chassis.
- Use of hybrid buses for public transport in large cities.
- Increasing use of multi-axle articulated transport vehicles for freight transport. This will be further encouraged by the four laning of national highways.



Introduction

Background: Global scenario

Motorization^a has been a major contributor to the increased mobility of people, goods and services, and consequently, economic progress. While this phenomenon has brought immeasurable benefits, it has not been without deleterious effects. These have primarily been in the form of increased pollutants emitted into the atmosphere from motor vehicle exhaust, congestion, haphazard urban growth and land use, increased dependency on oil, and other related problems.

The most important developing-world phenomenon is the extremely rapid rate of urbanization in many countries, especially Asia and Latin America. People residing in urban areas have to get to work, get to school, and shop. The goods they produce and consume have to be transported from their factories to their stores. The waste they generate must be collected and disposed of. All this requires transportation.

A major global concern is the increasing contribution of the transport sector to greenhouse gas emissions resulting from the use of fossil fuels, and their effect on global warming and climate change. The importance of energy used in transport and the emissions from different modes of transport has grown substantially in recent decades. This has been in response to a series of public policy objectives such as energy security, human health, safety, local environment and climate change and the economic affordability.

Motor vehicles are major sources of local, urban, and regional air pollution. The pollutants emitted by vehicles include sulphur dioxide (SO₂), lead (Pb)^b, carbon monoxide (CO), hydrocarbons (HCs), particulate matter (PM), and nitrogen oxides (NO_x). While petrol engines emit more CO and HC, diesel engines produce more NO_x and PM. Since all pollutants affect human health, it is necessary to consider them collectively when formulating emission regulations. Private-vehicle travel tends to generate larger amounts of emissions per unit distance travelled than do modes of public transport. According to a

^a The level of motorization is measured as the growth in ownership and use of motorized vehicles.

^b Leaded petrol been phased out in a number of countries, including India.

TERI estimate, if 50-odd bus passengers were to switch to two-wheelers instead, the impact on pollution will be 36 times worse; with cars, it would be 23 times worse (TERI 2001c). Clearly, many other factors are involved, including average vehicle occupancy rates, the age and maintenance level of the vehicle fleet, and so on.

Stringent emission standards and improved technologies

Although the burden on environment and health associated with motor vehicle use is pervasive and persistent, and the rapid growth of the world fleet presents a tremendous challenge, there is still reason for optimism. Both, industrialized and developing nations, have taken major steps in recent years to control vehicle emissions and improve fuel efficiency. Strong programmes in several countries have brought about impressive emissions reductions and increased fuel over the last thirty years, a promising example for countries with younger programmes. Emerging technologies, in combination with intelligent policies, offer hope for dramatic emissions reductions in the future. Automobile manufacturers are bringing forth new technologies such as catalysed particulate traps, continuously variable transmissions, lightweight materials, hybrid-electric drive trains, advanced gaseous-fuel engines, and fuel cell vehicles. Battery-electric vehicles and small sized cars are finding niche markets.

Technologies to reduce emissions from spark-ignition (i.e., petrol-powered) engines were first introduced in the United States and Japan in the late 1960s. Europe followed with similar regulations a decade later. Standards for exhaust emissions, and for evaporative emissions of volatile organic compounds (VOCs) from vehicle fuel systems, have become progressively more stringent in a trend that is likely to continue. Emissions from new vehicles in the most strictly controlled countries are 90% to 98% lower than they were before controls were applied. Other parts of the world are following this step-by-step approach to regulation, albeit with some lag.

The emissions from vehicles powered by compression-ignition (i.e., diesel) engines (including trucks, off-road construction vehicles, and railroad locomotives) are also being controlled by progressively stringent emission standards. This is being brought about by advance in engine technology and the development of aftertreatment technologies. Certain aftertreatment devices such as PM trap and DeNO_x catalysts hold the key to achieving Euro IV levels of emissions and depend heavily on the quality of diesel. Refineries are beginning to produce reformulated, very low sulphur fuels that enable advanced emissions technologies to be used in vehicles.

The adoption of more effective abatement technologies (generally in response to stricter emission standards) will lead to significant reductions in per-vehicle emissions rates. However, these will not automatically translate into equivalent reductions in total vehicle-related emissions due to rapid urbanization, motorization, the lag in adopting more recent vehicle pollution control devices (in part due to the need to upgrade fuel quality and fuel distribution systems), and the slow turnover of vehicle fleets, particularly in the developing world.

Urbanization and motorization

The developing portion of the world is characterized by low but overall rising incomes and a rapid rate of urbanization. Both these factors are likely to worsen air pollution in urban areas. Rising incomes combined with an increasing preference for personal mobility and travel particularly in the urban areas is likely to result in a pronounced increase in automobile ownership and bus transportation in much of Asia, Middle East, Eastern Europe, and parts of Africa. Growths in populations and gross domestic products (GDP), over the next few decades will see a strong increase in the worldwide vehicle fleet, especially in the rapidly industrializing countries of Asia. This growth is offsetting very successful efforts in many countries to reduce vehicle emissions.

Use of non-renewable, carbon-based energy sources

Fuels derived from petroleum now account for more than 96% of all the energy used in transportation. There has been no sign of any decrease in that percentage (IEA 2000). Other sources of transportation energy – coal, natural gas, alcohols, electric power – have been significant in particular places or times but all have been only minor fractions of the total.

According to the International Energy Agency (IEA), it is expected that in a business-as-usual scenario the consumption levels of liquid fuels (petrol and diesel) in the transport sector would be at least double today's in 25 to 30 years (IEA 2000; EIA/US DOE 2001). Thus, the use of liquid fuels will continue to predominate in the transportation sector.

The more pressing issue is not the availability of fuel but carbon dioxide (CO₂) emissions resulting from the production/manufacture and use of fuel, whether it is derived from conventional petroleum fuels, heavy oil, or natural gas. Switching from petroleum-like fuels to other fuels that emit less CO₂ during their manufacture and use could mitigate CO₂ emissions at least from their use in transport. This is the principal driving force behind the current interest in

fuels such as ethanol or methanol that are derived from biomass, and in fuels such as hydrogen or electric power that are derived from sources of primary energy that do not emit CO₂. Currently, there are many economic and technical barriers to the commercialization of these alternative fuels, but research can help overcome them.

Urbanization and motorization in India

The Indian population is fast urbanizing. The urban population is expected to grow from the current level of 300 million to about 400 million by 2010. The role of cities in the national economy has been growing, as the share of GDP over the national total has grown from 50% in the early 1990s, to 60% in 2000 (World Bank 2002). The extent to which Indian cities contribute to macro-economic performance will be closely linked to how efficiently their transport systems move the people and goods upon which their socioeconomic activities depend.

In the past 50 years, India's total population increased 2.8 times, the total urban population 4.6 times and the number of registered motor vehicles over 161 times (Figure 1.1). Urban transport has been a major concern particularly in large sized cities - particularly in the 35 with over one million people (2001 Census). In addition, there are 393 cities with a population between 100,000 and one million, and 3,975 cities with between 5,000 and 100,000 people.

Urban transport problems in India are becoming acute mainly because of rapid motorization. The increasing use of motor vehicles in cities has been rapidly changing the modal split structure. It has also helped to alter land use patterns from compact to more dispersed, which in turn, reinforces the use of personalized motor vehicles. One noticeable feature about growth of vehicles is the explosion in the number of two-wheelers (scooters, motorcycles and mopeds), cars and auto rickshaws in the absence of a good mass transport system. During the last decade the motor vehicle ownership in India (overall) grew roughly at 10% a year, while the growth in the metropolitan cities alone (with populations over one million) registered over 15%, significantly higher than the national average (MoST various years). This growth pattern is expected to continue with the growth of per capita incomes, especially in urban areas.

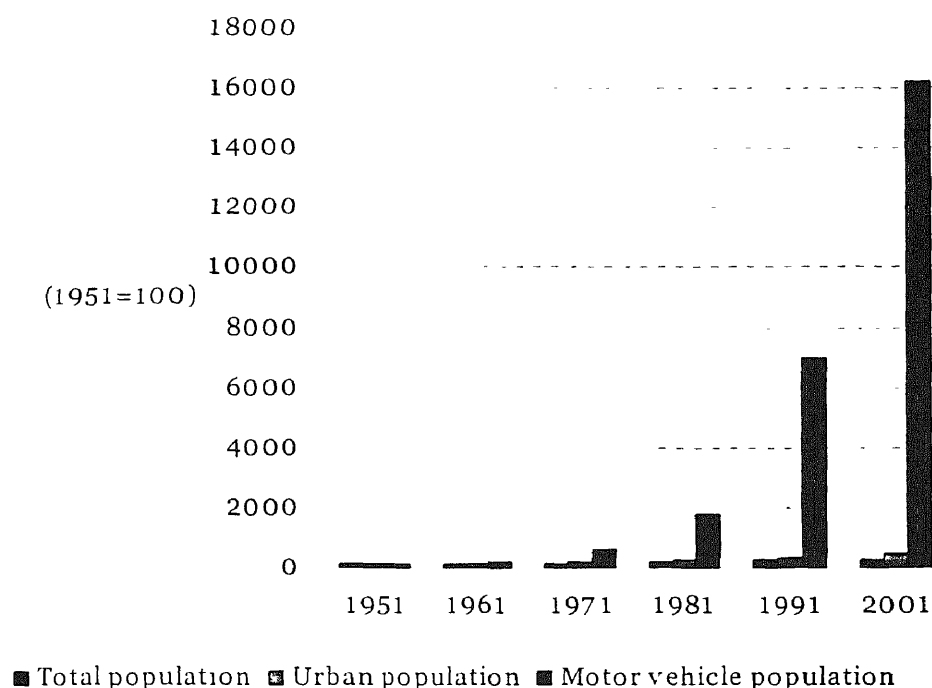


Figure 1.1. Growth of population and motor vehicle fleet in India since 1951

Key questions in the Indian context

As a result of air quality concerns, all types of vehicles have been subjected to increasingly stringent emission standards. Fuel specifications and engine technology both must go hand in hand but this would translate into high costs for vehicle manufacturers and the refineries. In a large but poor country such as India it is essential to evaluate the cost of different options especially if they yield comparable results in order to determine the most cost-effective solution. In view of the growing demand for clean fuels in the transport sector, it is important to determine the cost of supplying clean fuels to dispensing stations in major cities.

Technological advancements have allowed increased travel speeds, decreasing the importance of proximity. Individuals and firms are now willing to sacrifice nearness for other desirable land and building characteristics, such as space and a cleaner environment. Today, two overarching phenomena are shaping the pattern of human settlements. The first of these is urbanization and the second is decentralization – the tendency of these same urban areas to expand outwards into satellite towns and suburbs, generally at rates faster than the overall population growth.

Mobility systems affect urban growth in an important way because they make areas of a city more or less accessible, altering the land values and an area's attractiveness for various uses. Transportation investments often open up new areas for development. For instance, a highway on an urban fringe that facilitates suburbanization around the existing urban core.

Given the current situation in India, the following questions that influence product development strategy in automobile industry need to be addressed.

- 1 What are the trends in urbanization and motorization?
- 2 Is vehicle ownership likely to increase with GDP growth rates?
- 3 What is the impact on air quality in major cities and what are the major sources of pollution?
- 4 What are the health impacts and costs due to air pollution?
- 5 How is the trend in prescribing emission norms emerging and what is future action likely to be?
- 6 How, and to what extent, does motorized transport contribute to pollution?
- 7 Which are the emerging fuels and technologies?
- 8 What are the implications on fuel infrastructure development and fuel pricing?

Scope and objectives of the study

TELCO (TATA Engineering Locomotive Company Limited) commissioned TERI (The Energy and Resources Institute), New Delhi to develop an objective and well researched policy document that projects vehicular growth in the context of current policies and emerging trends in controlling vehicle emissions in the urban transport sector in India.

This study is expected to help TATA Engineering to assess and develop their research and product development strategy. More specifically, the objectives are

- to analyze the growth potential of different category of Indian vehicles over the next 20 years in India, its major states by analyzing the factors influencing the growth pattern. The impact of increasing the share of public transport on energy demand and emissions in urban areas has also been examined based on available literature;
- to analyze the connections between emissions of criteria pollutants and health and health costs by carrying out a literature review;
- to review the current and emerging environmental regulation for motor vehicles in India and abroad;

- to provide an overview of the current and future fuel quality standards in Europe, US, Japan and India, and international experience in the use of gaseous fuels (like CNG and LPG) and bio-fuels (like ethanol and bio-diesel) in motor vehicles;
- to provide an overview of the production and distribution infrastructure of liquid and gaseous fuels and factors affecting their pricing based on the current taxation structure in India;
- to review the status of current and future technologies for vehicular emissions control for stoichiometric and lean burn combustion, and
- to provide an overview of the development activities in electric, hybrid-electric and fuel cells vehicles in India and abroad.

Organization of the report

The report is divided into eight chapters.

Chapter 1 lays out the key economic and environment policy/issues that will influence the development of products in the future in the automobile industry and states the study's objectives.

Chapter 2 analyzes the various factors which influence vehicular growth and projections for vehicle population have been made for the period 2000/01 to 2020/21 for a number of states. The chapter also looks at the impact of increasing share of public transport on the energy and environment scenario of certain cities based on available literature.

Chapter 3 reflects upon connections between pollutant emissions (with particular emphasis on regulated pollutants) and health impact and health costs based on a literature review with a focus on India.

Chapter 4 provides an overview of environment regulations for motor vehicles in India, the European Union, the United States, and Japan. The chapter also presents a road map drawn up for the automobile industry and oil and gas companies for achieving progressively stringent tailpipe emissions from motor vehicles in different regions of the world.

Chapter 5 examines current policies for developing and promoting the use of cleaner conventional liquid fuels (diesel and petrol), gaseous fuels (CNG and LPG), and bio-fuels (ethanol and bio diesel) in the Indian transport sector, the European Union and the United States. The chapter emphasises the analysis of critical parameters which influence tailpipe exhaust emissions and the cost of upgrading Indian refineries to improve the quality of liquid fuel.

Chapter 6 studies the development of infrastructure for producing cleaner diesel and petrol, their distribution along with CNG and LPG and their pricing based on the country's current taxation structure.

Chapter 7 reviews technologies for post combustion emission control and the role of fuel quality in reducing the levels of pollutants. Part 1 presents an overview of the current catalyst technology for emission control commercially available. Part 2 deals with the emerging new technologies for emissions control for stoichiometric and lean burn combustion.

Chapter 8 gives an overview of the international experience in the development of new generation power packs for zero- or near-zero tailpipe emissions. The technologies discussed are electric, hybrid, and fuel cells.

The main objectives of this chapter are highlighted below:

- A study of the factors influencing a growth in the number of vehicles
- Project the vehicular population upto 2020/21 in states which have been selected because of their high vehicular growth rates and to estimate the growth rate of vehicles in this period.
- Review of the impact of increased share of public transport on the energy and environment scenario of certain cities based on available literature

In the past three decades, road transport has become an important means of moving people and goods. According to estimates of the Planning Commission, the roads carried just 11 per cent of goods and 28 per cent of passengers during 1950/51 and these figures during 1995 were 60 per cent for goods and 80 per cent for passengers.

India has one of the largest and most extensive road networks in the world covering more than 3.3 million kilometres. Roads cater to all types of traffic; long distance traffic is served by national highways and state highways, inter- and intra-district traffic by major district roads, feeder traffic connecting rural centres of production to market outlets by other district roads, and local traffic by village roads and urban roads. National highways span 58,112 km throughout the country and cater to around 45% of the total road transport demand (MoF 2003).

Between 1950 and 1996, the total number of registered vehicles grew 121 times. In 1998, the number of registered vehicles in India was over 48 million. The majority (over 70%) is two-wheelers comprising scooters, motorcycles, and mopeds. There are approximately 5.5 million cars/jeeps, 2.4 million three-wheelers such as auto-rickshaws, 2 million goods vehicles and 0.5 million buses. The proportion of private vehicles (two-wheelers and cars) to the total number of registered vehicles in India has increased from 65% in 1971, to 82% in 1999/2000.

Factors influencing the growth in numbers of passenger and goods vehicles

The level of motorization in any country/region is a function of several forces including investment, subsidy and tax policies, infrastructure design and planning, regulatory actions, level of urbanization and land use patterns that evolve in response to long-term transportation system evolution, cultural tendencies and habits, income levels and distributions, etc. Some of these factors are discussed in detail below:

Urbanization

An urban location has been defined by the Census of India as any place with a municipality, corporation, or notified town area or which has a minimum population of 5000, with at least 75% of the male working population engaged in non-agricultural services and with a population density of at least 400 per square kilometre (Ramchandran 1992). There is also a tendency for urban centres to cluster around a few major foci. Thus, around a metropolitan city, a number of smaller satellite towns develop which have close economic links with the main city.

The existence and proliferation of urbanization and metropolitan cities is due to the economies of agglomeration that are associated with industrial and trade activities. The secondary and tertiary sectors ('advance sectors') are usually located in urban centres and the level of productivity of labour is typically higher. In such centres, motorized road transport is the main mode of movement for both, passengers and freight. The increasing rate of urbanization and city size growth have both put the transport system under a lot of pressure. Urbanization trends manifest themselves in a growth in travel demand because urban populations travel more than rural ones. In part, this growth in travel demand is also because of the change in the structure of urban areas due to population growth as also increased sub-urbanization and growth of peri-urban areas. This is because with the high rate of growth of population in these urban areas and inadequacy of infrastructure, there is a tendency for people and businesses to shift their base to surrounding areas, leading to spatial expansion of the urban area. Finally, since transport is a derived demand, the growth in travel demand can be explained to a large extent through greater levels of activity arising from faster economic growth. Thus there is a strong correlation between urbanization, economic growth, and transport demand. The growth in travel demand has in turn obvious implications on the growth in vehicle number.

Apart from the growth in travel demand, other factors that influence the growth in vehicle population include a slower growth in the public transport infrastructure vis-à-vis the growth in travel demand resulting in a faster increase in personal mobility and intermediate public transport. In almost all urban centres, public transport has failed to meet the rising travel demand with the bus fleets having not grown much. Most existing fleets are in a very poor condition. Thus, with the public transport system in most of the urban areas lacking in terms of adequacy, efficiency, accessibility, and reliability, the personal modes of transport (scooters, motor cycles and cars/jeeps) have come to cater to a large portion of the travel demand. The changes taking place in the economy also affect the growth rate of the vehicle population—a faster growth in the services and manufacturing sectors compared to agriculture is likely to influence vehicle demand.

Urban context

Urbanization trends in India

India's urban population is growing at an average rate of 3 percent per annum. The urban population of the country has gone up significantly from 62 million (17% of the total population) in 1951 to 285 million (29%) in 2001 (Census of India, 2001, <http://www.censusindia.net/results/state.php?stad=A>). It is expected to increase to 504 million by the year 2021 (assuming a decadal growth of 37%). The number of metropolitan cities with a population of more than one million has increased from 5 in 1951, to 23 in 1991, to 35 in 2001 and is expected to become 51 by 2021 (Padam 2001). These urban centres are expected to grow at a high rate due to an increase in population as a result of both natural population growth and migration from rural areas and smaller towns. Tables 1 and 2 in Annex 2.1 give the urban population and the number of urban agglomerations by size class over the years. These tables show that the larger cities have grown very rapidly, though the growth rate is now tapering off. In the case of smaller towns (Class V & VI), the growth rate has been quite low, in fact it has even been negative in some years.

Urban transport trends

States that are characterised by high levels of urbanization are also the ones which have a large vehicle population (Annex 2.2, Table 1). These states also have high levels of Net State Domestic Product (NSDP). However, the rate of growth of vehicles outpaces the growth in the urban population. Table 2 in the

Annex 2.2 compares the rate of growth of population vis-à-vis the growth rate of vehicles for some of the cities with a population of more than 1 million.

The annual rate of growth of motor vehicles in India over the last decade as estimated from motor vehicle statistics was around 8.5%. A majority of the motor vehicles (about one-third of the total vehicles in the country) are concentrated in the urban centres of the country, especially in the metropolitan cities (with a population of more than 1 million), which have around 8 per cent of the country's population. For instance, Delhi which is home to around 1.2% of the country's population, accounts for over 7% of the total vehicle population of the country. The dominance of personalized modes of transport has been a characteristic feature of the growth in motor vehicle population in the city. The share of registered buses, which cater to about 53% of the total passenger travel demand, has been a paltry 1%. Even the share of the intermediate public transport, i.e. three-wheelers and taxis, as a percentage of total motor vehicles, has gone down from 4.3% in 1985 to 3.2% in 1998 (TERI 2000). These metropolitan cities are characterized by high income levels.

About 70%–75% of the fleet on an average is comprised by two-wheelers in the urban centres (two-wheelers constitute around 45% only in Mumbai and Kolkatta which could be because of an efficient railway system/metro for urban passenger movement). Cars and jeep cover around 15% of the fleet, three-wheelers are around 5%, and taxis 1%. Buses comprise around 1.5% while trucks form 5% of the total vehicle fleet.

Income levels and prices of vehicles

Passenger transportation needs can be satisfied by two-wheelers, cars/jeeps, three-wheelers/taxis and buses. The individual's decision to use any of these vehicle segments is driven by his/her level of income to a very large extent. Rising incomes are expected to lead to a shift up the 'transport ladder' from public transport to two-wheelers and from two-wheelers to cars. Hence, per capita income is an important economic variable determining the level of motorization or vehicular population growth rate. Income levels are an important determinant of vehicular population in the urban areas which are characterized by levels of prosperity, far higher than those in the rest of the country. For instance, per capita NDP, an indicator of prosperity, in Greater Mumbai is 32439 rupees at current prices, which is more than three times the national average of 9322 rupees (Socio-Economic Review of Brihan Mumbai 1997–98).

Also with competition (a post-liberalization phenomenon), there are a great variety of vehicles available in each vehicle category. Within a particular category, the decision to purchase a particular variety of vehicle is driven by the income level and the price of the vehicle.

Government policies

Liberalization

Over the past years the Indian automobile industry, production trends, and pattern of vehicle ownership have undergone significant changes. The automobile industry has gone through three distinct phases: the early regime of licensing until 1983; partial liberalization in 1983/84, which led to the entry of Maruti and the proliferation of two-wheelers and LCVs (light commercial vehicles); and the phase in the 1990s when economic reforms were introduced in the economy as a whole. The car industry was delicensed in May 1993. It is now flooded with models from new and existing players, and there has been a visible shift from a constrained supply situation to a surplus.

Taxation policies

The Government's taxation policy towards the automobile sector has also had a significant impact and has undergone significant changes over the past two decades. Till 1987, the government followed a discriminatory policy of charging a lower excise duty on fuel-efficient cars of engine capacity less than 1000 cc. Maruti Udyog Limited benefited from this policy and was able to maintain a lower price than other manufacturers. The liberalization process that began in 1991 was also accompanied by a rationalization in the excise duty structure to reduce the multiplicity of rates. In the pre-1999 period, there were 11 *ad valorem* rates of basic excise duty: 5%, 8%, 10%, 12%, 13%, 15%, 18%, 25%, 30%, 32%, and 40%. These rates were reduced to three in the budget of 1999/2000—a central rate of 16%, a merit rate of 8%, and a demerit rate of 24%. At present, the rate of excise duty for commercial vehicles is 16%. Within this category, motor vehicles in which a chassis is fitted with the engine, the excise duty also includes 10,000 rupees per chassis (this has been introduced in the Union Budget of 2003/04 for promoting body building by integrated bus and truck manufacturers). For vehicles that are designed for transportation of not more than 6 persons and between 6 and 12 persons, the rate of excise duty is 24%. The duty on two-wheelers and three wheelers is 16% (<http://www.cbec.gov.in/cae/excise/cx-tariff/cx-tariff.html> as on 22 March 03). A merit excise duty of 8% is charged on electric vehicles. In addition to the

excise duty, states also charge a uniform sales tax of 12%. Similarly, the customs duty structure has been also rationalized. At present there are two levels of import duties applicable to motor vehicles: 30% and 105%. The rate of 105% applies to vehicles that are meant for the transport of persons (not more than 10) and two-wheelers. For other motor vehicles, motor vehicle parts and accessories, the rate of 30% is applicable

(<http://www.cbec.gov.in/cae/customs/cs-abc.html> as on 22 March 03).

Customs duty on catalytic converters and its parts has been reduced to 5% on environmental consideration. In the Budget of 2003/04, a National Calamity Contingent Duty of 1% has been imposed on two-wheelers, motorcars, and multi utility vehicles for a period of one year.

Other factors influencing the demand for goods vehicles

The demand for goods vehicles has grown substantially over the past years and there are several factors responsible for their growth. In 1950/51, the railways carried bulk of the total goods traffic (around 89%), the roads carried only 11%. Today, roads carry over 70% of the total freight traffic also evidenced by the rapid growth in truck population during this period. The number of trucks, which was around 82 thousand in 1951, grew to 1877 thousand in the year 1999/2000. The share of road transport in freight traffic is likely to increase further. One factor that could be responsible is the capacity constraint of the railways and the marked preference of users for road transport. This is due to a variety of factors: the railways lack flexibility in movement and do not provide door-to-door service, trucks are more easily available than railway wagons, rating policy of railways (freight rates by rail are in some cases, more than those by road), improvement in the quality of roads (state and national highways) and improvement in vehicle technology (the introduction of multi-axle vehicles (MAV)). A 3-axle MAV is reported to be 1.6 times as productive as a 2-axle rigid truck (AITD 1999). The MAVs also have lower operating costs compared to 2-axle vehicles and need a smaller crew to operate them for a given payload. Substantial improvement in the quality of roads and highways has taken place over the past few years mainly on account of the National Highway Development Project, which entails expansion of existing 2-laned highways to 4/6 lanes and strengthening of existing lanes along nearly 13000 km. of road. The project comprises 5846 km of a Golden Quadrilateral (G-Q) connecting Delhi, Mumbai, Kolkatta and Chennai and 7300 km of north-south and east-west corridors connecting Srinagar- Kanyakumari and Silchar-Porbandar. Phase I of the project is scheduled for substantial completion by the end of 2003. However, no

study or survey has been done to measure the impact of the technological and road quality improvements on the trucking industry.

Methodology

This section discusses the methodology used for making projections of vehicular number for the selected states.

Criteria for choosing states

States which have been chosen are those characterized by high vehicle populations and rates of growth. Some important cities identified by the Mashelkar Committee Report in the Auto Fuel Policy Report as facing very rapid vehicular growth and high vehicular pollution are also situated in these states. The states that have been considered are Andhra Pradesh, Bihar, Delhi, Gujarat, Karnataka, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal. The rest of the states have been clubbed together as Rest of India.

The vehicular growths in selected cities with more than 1 million people were also analysed. However, in absence of data on relevant socio-economic variable like NDP, per capita NDP etc. on a city level, detailed study and projections of the same was not carried out.

Vehicle categories

The vehicle categories considered are, two-wheelers, cars and jeeps, three-wheelers, taxis, buses, light commercial vehicles (LCVs) and trucks. For making projections, econometric equations have been established. The available data on vehicle population for these states is from 1980/81 to 1999/2000. Projections have been made for the years 2000/01 to 2020/21.

To arrive at the total number of vehicles in the various categories at the all-India level, the vehicle numbers in the states have been aggregated together.

Explanatory variables

As has been mentioned earlier, income, price, population, level of urbanization, taste, etc. are factors which influence the vehicle population. However, for some variables data are either not available or not sufficient to arrive at any significant relationship. For instance for price of vehicles the wholesale price index can be used as an indicator. However this index is not sensitive enough to capture state and inter-temporal variations. Another problem in using price as a factor is non-availability of data and a difficulty in arriving at an average price index for vehicles, as there is a wide variety available within each category of vehicle.

The relationships between vehicle population in the states and factors such as rate of urbanization, road length, population, index of industrial production (IIP) etc. have also been studied. While population and rate of urbanization are relevant factors for personal vehicles, intermediate public transport (three-wheelers and taxis) and public transport (buses), for LCVs and trucks relevant factors are road length and IIP. However the relationship with rate of urbanization and population (total or urban) could not be captured in the econometric equations for most cases. This could be because of the limited number of data points (only for 1981, 1991 and 2001 as reported by the Census of India). The industrial production (which can be captured by the IIP) is a very important factor that can influence the demand of goods vehicles. However, IIP is an index designed to measure changes in the level of output in the industrial sector of the economy and a relationship with IIP alone would not be able to capture the demand for goods vehicles generated by activities such as agriculture, etc. The impact of the growth in road length could not be captured in the econometric equations.

The income effect has been captured through the states NDP or per capita NDP. In order to eliminate the price effect (i.e. inflation), these variables have been taken at constant prices (1993-94 prices). It was found that NDP had a significant influence in the growth of all categories of vehicles. In case of personal vehicles i.e. two-wheelers and cars and jeeps, per capita NDP was used as an explanatory variable. Here per capita NDP is used as a proxy of the income that an individual has, which drives the decision to purchase personal vehicles. For intermediate transport vehicles, i.e. three wheelers and taxis, and buses, NDP at constant prices and rate of urbanization (in some cases) were used as explanatory variables.

The number of good vehicles has been projected by analysing past trends and studying their relationship with NNP, which covers all the sectors of the economy (agriculture, manufacturing, mining etc.) responsible for generating a demand for goods vehicles.

For the purpose of projecting vehicle number, the rate of growth of NDP and per capita NDP for each state was assumed as the basis of their growth rates in the past two plan periods (8th and 9th). For the country as a whole, the rate of growth of NDP has been assumed at around 6% per annum.

Model

For two-wheelers, cars and jeeps, three-wheelers, taxis and buses, time series analysis has been used. In this, the cumulative vehicle registration number (as reported by the Ministry of Road Transport and Highways in Motor Transport Statistics) which are reported annually, have been analysed for each state to make future projections (MoRTH various issues). The regression equation takes the following form:

$$Y_t = a + b \cdot X_t + U_t$$

Where Y_t is the number of vehicles in a time period t , a is the constant term, X_t is the value of the explanatory variable (NDP or per capita NDP) in time period t , b is the coefficient of the explanatory variable and U_t is the error term.

However, good econometric equations using this technique could not be established for LCVs and trucks primarily because of anomalies in the reported figures (for instance in some years there are very large drops in the cumulative registration figures which cannot be explained). Hence, in case of LCVs and trucks, sales data (as reported by Society of Indian Automobile Manufacturers in their statistical profile publications) has been analysed. The sales data is available for the period 1993 to 2000, which is not enough for carrying out a time series analysis. Hence, pool data analysis has been used to establish econometric relationships and for making projections. In this kind of analysis, the data over the years and across the states are pooled together and then regressions are run to establish the relationships. The regression is of the following form:

$$Y_{it} = a + b \cdot X_{it} + U_{it}$$

Where i denotes the cross sectional units (i.e. various states) and t denotes time. The variations across time have been captured by introducing time dummies.

The exact econometric equations for each category of vehicle for the selected states are given in Annex 2.3. The explanatory power of the equations in all cases was above 0.80. The only exception was in case of Bihar for two categories of vehicles (two-wheelers and cars & jeeps), however, for consistency these equations were used for projection purposes.

Results

The projected number of vehicles and their compound annual rate of growth (CAGR) over the period 2001/2021 in each vehicle category for the states are given in Tables 2.1 to 2.7.

There are certain caveats though, which have to be kept in mind while looking at the projections. The projections are based on an analysis of the past trends in the growth of the vehicular fleet and the relationship of vehicle demand with income. However, there were certain severe limitations in data availability and consistency. Hence these numbers provide only the broad direction in which the vehicular fleet is likely to grow in future.

In addition, there are certain exogenous factors, which can also impact the vehicular growth. These include changes in government policy (for instance greater emphasis on public transport system, introduction of metros and urban rail systems, discouraging private vehicles), initiatives taken by courts (like those which have been taken by the Supreme Court in Delhi and the High Court in Mumbai), greater level of urbanization than expected (with growing population and road congestion there might be rapid growth of satellite/new towns), technological changes (for instance, increased use of multi-axle vehicles in the heavy commercial vehicle category), etc.

Table 2.1 Past and projected number of registered two-wheelers for states (in 000's)

States	Past				Projected					CAGR (in%) 2001-21
	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16	2020-21	
Andhra Pradesh	142	436	1097	2067	3007	4461	6234	8498	11369	6.88
Bihar	75	214	686	921	764	981	1244	1550	1903	4.67
Delhi	345	665	1221	1876	2644	3652	5077	6949	9395	6.54
Gujarat	213	669	1412	2364	3411	4714	6488	8753	11627	6.32
Karnataka	225	497	1031	1600	2797	4006	5597	7676	10378	6.78
Maharashtra	364	895	1736	2676	4143	5817	8011	10841	14471	6.45
Rajasthan	102	228	696	1178	1848	2649	3739	5148	6954	6.85
Tamil Nadu	158	439	1070	2102	3702	5557	7969	11140	15288	7.35
Uttar Pradesh	231	558	1332	2057	3128	4319	5844	7669	9835	5.89
West Bengal	93	195	351	715	1163	1675	2312	3119	4135	6.55
Rest of India	582	1469	3566	5843	7049	12241	19287	28588	40692	9.16
All-India	2528	6264	14197	23397	33656	50073	71801	99930	136046	7.23

Table 2.2 Past and projected number of registered cars and jeeps for various states (in 000's)

States	Past				Projected					CAGR (in%)
	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16	2020-21	2001-21
Andhra Pradesh	26	57	102	167	243	338	460	615	812	6.22
Bihar	39	63	107	125	123	155	193	238	289	4.35
Delhi	119	180	398	634	1015	1458	2088	2926	4030	7.14
Gujarat	45	101	192	311	437	594	808	1080	1425	6.09
Karnataka	75	109	159	238	385	531	722	970	1291	6.23
Maharashtra	227	316	431	536	766	987	1271	1630	2083	5.13
Rajasthan	25	40	92	144	224	314	435	592	792	6.51
Tamil Nadu	72	98	236	320	466	645	874	1173	1562	6.24
Uttar Pradesh	50	87	127	182	283	377	497	640	809	5.38
West Bengal	130	178	284	342	433	551	689	861	1073	4.64
Rest of India	209	314	583	891	1119	1783	2676	3848	5366	8.15
All-India	1017	1544	2711	3890	5495	7733	10714	14572	19530	6.55

Table 2.3 Past and projected number of registered three-wheelers for various states (in 000's)

States	Past				Project					CAGR (in%)
	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16	2020-21	2001-21
Andhra Pradesh	10	20	38	62	148	220	314	437	597	7.22
Bihar	4	7	22	38	52	73	98	127	162	5.82
Delhi	20	32	63	79	138	206	307	455	672	8.25
Gujarat	31	95	148	198	339	489	690	960	1320	7.04
Karnataka	21	30	51	111	244	365	527	744	1033	7.48
Maharashtra	50	106	186	336	475	684	946	1308	1785	6.84
Rajasthan	5	10	21	32	52	75	106	148	205	7.12
Tamil Nadu	12	18	46	79	137	204	293	413	573	7.42
Uttar Pradesh	5	13	32	55	95	136	186	248	324	6.35
West Bengal	1	2	10	17	29	43	61	85	116	7.11
Rest of India	22	72	158	364	604	901	1281	1766	2381	7.10
All-India	181	405	775	1373	2313	3396	4810	6690	9169	7.13

Table 2.4 Past and projected number of registered taxis for states (in 000's)

States	Past				Projected					CAGR (in%)
	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16	2020-21	
Andhra Pradesh	3	6	9	20	33	47	66	90	122	6.81
Bihar	5	10	22	28	39	53	69	89	112	5.40
Delhi	6	9	10	14	19	25	35	50	72	6.94
Gujarat	2	7	11	28	37	54	78	109	151	7.34
Karnataka	3	7	8	13	32	46	65	91	125	7.11
Maharashtra	32	40	43	59	80	103	134	175	230	5.40
Rajasthan	1	3	9	13	20	26	32	40	49	4.59
Tamil Nadu	9	17	18	22	58	88	129	184	257	7.70
Uttar Pradesh	4	6	13	30	38	54	73	97	126	6.16
West Bengal	18	22	34	42	54	70	91	118	154	5.38
Rest of India	35	46	72	113	201	287	397	536	714	6.53
All-India	118	172	249	384	610	853	1169	1578	2110	6.40

Table 2.5 Past and projected number of registered buses for states (in 000's)

States	Past				Projected					CAGR (in%)
	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16	2020-21	
Andhra Pradesh	10	12	32	38	53	73	99	134	179	6.32
Bihar	9	14	15	18	22	27	34	41	49	4.07
Delhi	8	14	19	28	39	53	73	99	136	6.48
Gujarat	9	21	25	33	42	56	74	98	131	5.87
Karnataka	13	17	22	34	54	75	102	138	187	6.38
Maharashtra	18	22	28	42	63	85	115	155	208	6.15
Rajasthan	7	11	23	34	50	72	101	139	191	6.92
Tamil Nadu	13	21	28	36	45	60	79	105	140	5.80
Uttar Pradesh	14	20	24	29	35	43	52	64	79	4.15
West Bengal	12	17	22	26	32	39	49	62	79	4.63
Rest of India	40	62	94	145	196	267	357	473	619	5.92
All-India	154	232	332	462	631	849	1135	1509	1999	5.93

Table 2.6 Past and projected number of sales of LCVs for states (in 000's)

States	Past		Projected				CAGR (in%) 2001-21
	1993	2000	2005	2010	2015	2020	
Andhra Pradesh	2	6	5	6	8	9	1.83
Bihar	1	2	2	3	3	4	2.48
Delhi	3	4	3	4	6	7	2.83
Gujarat	10	15	9	11	13	16	0.53
Karnataka	1	1	4	5	6	8	8.52
Maharashtra	6	6	5	6	7	9	1.73
Rajasthan	2	3	5	7	8	10	5.41
Tamilnadu	6	4	5	6	7	9	4.13
Uttar Pradesh	4	4	6	7	8	9	4.05
West Bengal	6	10	6	7	9	10	0.19
Rest of India	19	19	15	18	22	26	1.52
All-India	60	76	66	80	97	117	2.19

Table 2.7 Past and projected number of sales of trucks for states (in 000's)

States	Past		Projected				CAGR (in%) 2001-21
	1993	2000	2005	2010	2015	2020	
Andhra Pradesh	3	4	5	6	7	9	4.62
Bihar	1	3	2	3	3	3	0.79
Delhi	2	4	3	4	5	7	2.81
Gujarat	5	8	8	10	13	15	3.50
Karnataka	2	3	4	5	6	7	4.58
Maharashtra	3	3	5	6	7	8	4.91
Rajasthan	2	7	5	6	8	9	1.62
Tamilnadu	5	2	5	6	7	9	6.48
Uttar Pradesh	2	5	6	7	8	9	2.97
West Bengal	5	6	5	7	8	10	2.47
Rest of India	13	16	15	17	21	25	2.29
All-India	43	60	63	76	92	112	3.13

Annual registrations

For two-wheelers, cars and jeeps, three-wheelers, taxis and buses, the new registrations annually at the all-India level have been given in Table 2.8. These estimates have been arrived at by deducting the previous year's registration figures from the given year's registrations. Table 2.8 also gives the compound annual growth rate of these vehicles over the period 2002/03 to 2011/12.

Table 2.8 Annual registration of vehicles at all-India level (in 000's)

Vehicle category	1996-97	2002-03	2006-07	2011-12	CAGR (in %)
Two-wheelers	2405	3137	3900	5068	5.47
Cars and Jeeps	399	430	535	695	5.48
Three-wheelers	275	204	254	334	5.62
Taxis	36	46	57	74	5.41
Buses	34	41	51	67	5.56

Comparison with other studies

The NCAER carried out a similar study on projections of automobile demand (NCAER 2002) whose results are given in Table 2.9. However, comparisons cannot be made because the NCAER has projected sales of vehicles while this study projects registration numbers for most vehicle categories. Also, vehicle categories differ in the two studies—in the NCAER study, motor cycles, scooters and mopeds have been considered separately while in this study these have been taken together as one category. Also, in this study the rate of growth of the explanatory variables is based on past trends. Another difference in the two studies is the time periods considered in analysing the data while making projections. In the NCAER study the data are from 1995/1999.

Table 2.9 NCAER automobile demand projections (in 000's)

Vehicle category	2002-03	2011-12	CAGR (in %)
Passenger car	613	1227	8.0
Motor cycles	3270	10669	14.0
Scooters	876	1124	2.8
Moped	480	616	2.8
MUV	130	282	9.0
Three-wheelers	213	382	6.7
Buses	28	44	5.2
LCV	50	71	4.0
Trucks	60	89	4.5

Source: NCAER, 2002. The growth rates assumed by NCAER vary between 5.5 to 6.5% per annum.

Vehicle ownership: comparison with other countries

Vehicle ownership per thousand is much lower than that in the developed countries. For instance car ownership (vehicle registrations) per thousand people in 1995 in the US, was 517, 356 in Japan, 415 in UK, 86 in Mexico, 24 in Thailand, 11 in Indonesia (Bose 2001). India and China in comparison had 4 and 3, respectively. Delhi, which has the highest vehicle ownership and per capita income levels in India, had 54 cars per thousand of people in the year 1995/96.

This is likely to go up to 188 by the year 2020/21. Hence while there is likely to be a substantial increase in the vehicle ownership it would still be much lower than the levels, which exist in developed countries. However, one cannot simply compare the level of ownership across different countries as there are differing factors and conditions influencing it.

Impact of improved public transport

One of the highly recommended strategies for dealing with increasing vehicular congestion and pollution in the urban areas is to strengthen the public transport system. According to a TERI study (TERI, 1997) substantial gains in energy and environment can be achieved by improving the public transport system in the metropolitan cities of the country. In this study a comparison has been made between a business-as-usual scenario and an alternative scenario with very high public transport penetration. In the former scenario, the current trends of growth in registration of vehicles in each of the cities are assumed to continue, with buses meeting around 66%, 26%, and 59% of the travel demand in Delhi, Kolkata, and Bangalore respectively for the year 2010/11. In the alternative scenario, public transport meets around 80% of the travel demand. This implied an increase in the number of buses by 21% (Delhi), 212% (Kolkata) and 35% (Bangalore). The energy savings are reported to be of the order 16%, 53%, and 21% for Delhi, Kolkata, and Bangalore respectively for the year 2010/11. The percentage reduction in the annual emissions loading for various pollutants for the three cities is as follows. For CO, the reduction is around 30% for Delhi, 66% for Kolkata and 54% for Bangalore. For HC, the total emissions reduce by 34% for Delhi, 71% for Kolkata and 66% for Bangalore. For TSP, it is 14%, 50% and 32% (Delhi, Kolkata, and Bangalore).

Introduction

Air pollution is defined as an imbalance in air quality that causes deleterious effects. Pollution occurs when gaseous emissions (vapours), solid, or liquid particles are released into the atmosphere. Emissions have both natural and man-made sources, however in terms of ambient air pollution levels, the release of these pollutants are governed predominantly by human activities as a result of the use of fossil fuels. Urban air quality is increasingly being recognized as a major public health and environmental issue in developing nations. Increasing urbanization and even faster motorization have been the major factors leading to an increase in energy demand and hence high emissions of air pollutants.

Atmospheric pollutants commonly associated with motor vehicles include carbon monoxide (CO), oxides of nitrogen (NO_x), hydrocarbons (HCs) and other volatile organic compounds (VOCs), ozone (O₃), sulphur dioxide (SO₂), lead (Pb)^a, particulate matter (PM) and other toxic substances such as benzene, aldehydes etc. which are known carcinogens. The health impact caused by these pollutants has been associated to severe congestion and pollution levels in cities. Inhalation is the main route of exposure to air pollutants. Exposure by inhalation directly affects the respiratory, nervous and cardiovascular systems in humans resulting in impaired pulmonary functions, sickness, and even death.

The nature and extent of potential health effects that can result from exposure to pollutants depends on a number of factors. These include physical and chemical properties of the pollutant, toxicity level, genetic makeup, personal habits, age, sex, diet, health status of the population, concentration of the pollutant in the air, dose received by the individual, route and duration of exposure. These interlinked factors determine the magnitude of the health effect.

Pollutants such as NO_x and SO₂ apart from causing pollution locally and affecting health are also transboundary pollutants causing wind-borne acid deposition at the regional level. Acid rain is associated with extensive forest

^a This originates mainly from the use of leaded petrol containing tetraethyl or tetramethyl lead for octane boosting. High levels of Pb is known to damage the kidney, liver, reproductive system, blood formation, central nervous system, and brain function. Health effects associated with the use of Pb additives in petrol have led to the elimination of leaded petrol in several countries, including India.

decline and contributes to corrosion of materials, structural damage to monuments and buildings, and impairment of sensitive aquatic ecosystems. The gases associated with motor vehicle use such as carbon dioxide (CO₂), chlorofluorocarbons (CFCs), HC, and nitrous oxides (N₂O)) contribute to the global greenhouse effect as well as to the destruction of the protective ozone (O₃) shield. Hence pollutants released in from vehicular sources can have significant impacts on regional and global environmental problems.

This chapter provides an overview of the impact of criteria pollutants (namely, CO, HC, O₃, NO_x, SO₂, Pb, and PM) on health (localized impact) and the associated health cost and do not cover regional and global environmental issues. Particular emphasis is also laid on the motor vehicle related air pollution in India and the role automobile and fuel technologies can play in bringing down tailpipe exhaust emissions.

Health effects of pollutants from motor vehicles

The primary pollutants emitted by motor vehicles include HC and NO_x, the precursors for ground level ozone and CO. In most large Indian cities the motor vehicle related air pollution is already serious and worsening. While the problem of diesel smoke and PM is the most apparent. Damage from pollutants can result to the immune system, as well as neurological, reproductive (e.g., reduced fertility), developmental, and respiratory problems. The dose-response functions for these pollutants are usually based directly on ambient concentrations.

While the tailpipe emissions of CO, HC, NO_x, PM for new vehicles are subjected to progressively stringent emission standards (see Chapter 4 for details), there are a large number of other toxic components. These include aldehydes, benzene, polycyclic aromatic hydrocarbons etc. In general, exposure to toxic air pollutants at sufficient concentrations increases chances of cancer or other serious health effects. Hundreds of pollutants are harmful to human health but only the main pollutants are discussed below. Effects of short term and long-term exposures of these pollutants and their health impacts are briefly discussed below.

Carbon monoxide (CO)

Carbon monoxide is absorbed through the lungs forming carboxyhaemoglobin (COHb) in the blood, which reduces the blood's oxygen-carrying capacity. CO uptake impairs perception and thinking and causes drowsiness, angina, unconsciousness, and even death. The relationship between ambient CO concentrations in air and COHb levels in blood depend primarily on the

duration of exposure. Carbon monoxide is considered toxic at concentrations much higher than found in typical urban environments and epidemiological studies are unable to correctly identify the full health impact of ambient CO levels. The health impact, of CO under varied concentrations is elaborated in Annex 3.1.

Ozone (O_3)

The effects of ozone have been seen even for short duration exposures (as little as five minutes). The effects become pronounced during longer periods of exposure (about six hours). Short-term adverse health effects include eye, nose and throat irritation, coughing, throat dryness, thoracic pain, chest tightness, and nausea. Longer-term health effects have been seen to affect the respiratory system causing chest discomfort, wheezing and asthma attacks. The health impact of O_3 under varied concentrations elaborated in Annex 3.2.

Nitrogen dioxide (NO_2)

Exposure to NO_2 is linked with susceptibility to respiratory infections and increased airway resistance in asthmatics and decreased pulmonary function. The relationship between outdoor NO_2 exposure and acute health effects however has not been demonstrated consistently from epidemiological studies (World Bank 1997a). The health impact of NO_2 under varied concentrations is given in Annex 3.3.

Particulate matter (PM) and finer particles

Particulate matter can be solid or liquid droplets of diameters ranging between 0.002 and 500 micron and remain suspended in the atmosphere from a few seconds to several months. Suspended particulate matter (SPM) is composed all particles having a diameter less than 100 microns which tend to remain suspended in the atmosphere for a long period of time. The health impact of PM depends on parameters such as size, acidity, solubility, oxidizing potential etc. Exposure to elevated levels of particulate matter has strong association with increased morbidity, mortality from respiratory-related illnesses and moderate evidence to causing lung cancer and cardiovascular conditions. Current epidemiological studies are unable to define a threshold below which no effects occur (WHO 1999). Evidence from epidemiological studies consistently point out associations between short-term exposure to PM to acute effects such as increased mortality and increased rates of hospital admissions for respiratory illnesses. There have been only limited studies on the long-term health effects of

PM and these are referred to mortality and respiratory morbidity. Studies have pointed out that long-term exposures can reduce the life expectancy of those exposed in the order of 2–3 years (WHO 1999).

Adverse health effects from inhaling particulates depend not only on the mass but more importantly, on the size of particles. Smaller particles penetrate deeper into the respiratory tract and can be more toxic. The respirable suspended particulate matter (RSPM) concerns to SPM having a diameter less than 10 microns (PM_{10}) and are small enough to enter the respiratory tract and pulmonary system of human beings. Similarly, $PM_{2.5}$ denotes SPM having a diameter less than 2.5 microns. Studies clearly point out that the health effects of particulates are largely associated with fine particles (less than 2.5 microns in size), but very little is known about the effects of individual components or characteristics of particulates (WHO 1999a). The health impact of PM and finer particles are elaborated in Annex 3.4.

The contribution of fine and ultra fine particles from the transport sector varies considerably from place to place. For instance, a study in the UK shows that 25% of RSPM (PM_{10}) and 60% of ultra fine particles (i.e. of $PM_{0.1}$ emissions) are reported to come from road transport (CONCAWE 1999b). Another study in Australia reports that automotive exhausts account for 13% of PM_{10} and 6% of primary $PM_{2.5}$ (CONCAWE 1999b).

Sulphur dioxide (SO_2)

The effect of SO_2 has been associated with reduced lung function and increases in the risk of mortality and morbidity (World Bank 1997a). Adverse health impacts include coughing, phlegm, chest discomfort, and bronchitis. A number of epidemiological studies in the United States have concluded that direct effects of SO_2 are not significant, however studies in Europe have found significant correlations with acute mortality and respiratory hospital admissions. The health impact of SO_2 under varied concentrations is given in Annex 3.5.

Other air toxics

Benzene

Benzene is present in both exhaust and evaporative emissions and is known to have toxic and carcinogenic effects (see Annex 3.8). Its effects are associated with the central nervous system as well as the haematological and immunological systems. Risk from life time exposure can cause leukemia and even death.

Polycyclic aromatic hydrocarbons (PAH)

These compounds are generally absorbed in the lungs and are mutagenic and carcinogenic. Some of the known carcinogenic PAHs include benzo (a) pyrene, benzo (b) flouranthene, benzo (a) anthracene, cyclopenteno (c-d) pyrene.

Aldehydes

Formaldehyde and other aldehydes are absorbed in the respiratory and gastrointestinal tracts. Adverse health effects include eye irritation, irritation of mucous membranes, cough, nausea, and shortness of breath. Formaldehyde is of particular interest due to its high photochemical reactivity in ozone formation and its suspected carcinogenicity (see Annex 3.8).

Sources of pollutants

Pollutants in the ambient air are contributed by many sources, of which motor vehicles are one. According to a WHO study, the sources of air pollution resulting from human activities can originate from three types of sources, as given below (WHO 1999).

- 1 Stationary sources which can be divided into
 - a Rural areas such as agricultural production, mining and quarrying
 - b Industrial point and area sources such as manufacturing chemicals, nonmetallic mineral products, basic metal industrial, power generation, as well from the unorganized sector and small scale industries
 - c Community sources such as heating of homes, refuse burning.
- 2 Mobile sources: these comprise any form of combustion from petrol, CNG, LPG, and diesel powered vehicles; aircraft including line sources and fugitive dusts from vehicle traffic.
- 3 Indoor sources: Emissions from the use of traditional fuels for cooking, domestic heating as well as from personal tobacco smoking. Annexes 3.1 to 3.8 provide a broad description of sources of different types of pollutants in the ambient air.

In India, due to the absence of emission inventories and source apportionment studies it is difficult to quantify the contribution of automobile exhaust to the different pollutants present in the air. Some studies have been carried out in the past in Delhi and Mumbai between 1988 and 1995 to estimate the contribution of automobile exhaust of some criteria pollutants to the ambient air (MoPNG 2002). The estimates vary considerably (Table 3.1). These

studies show that the contribution of auto exhaust emissions to the overall emissions load of CO is high, NO_x is moderately high but SO₂ is negligible. PM however has varied sources and their relative contribution from individual sources is still not known. Sources of particulates include, road dust, re-suspended soil dust, marine aerosols, burning of refuse and vegetation, emissions from the use of traditional fuels for domestic cooking needs, vehicular emissions, industries, power gensets, natural dust, building activities, and industrial emissions, etc. A TERI study reports that natural dust is the predominant source of PM (TERI 2001a).

Table 3.1 Motor vehicle's contribution to pollutants in Delhi and Mumbai

Pollutant	Range	Pollutant	Range
<i>Delhi</i>		<i>Mumbai</i>	
CO	Transport: 76 - 90 % Industrial: 37 - 13 % Domestic and other sources: 10 - 16 %	CO	Transport: 92% Industrial: 8% Domestic and other sources: Nil
NO _x	Transport: 66 - 74% Industrial: 13 - 29% Domestic and other sources: 1 - 2%	Nox	Transport: 60% Industrial: 40% Domestic and other sources: Nil
SO ₂	Transport: 5 - 12% Industrial: 84 - 95% Domestic and other sources: nil - 4%	SO ₂	Transport: 2 - 4% Industrial: 82 - 98% Domestic and other sources: Nil - 16%
PM	Transport: 3 - 22% Industrial: 74 - 16% Domestic and other sources: 2 - 4%	PM	Transport: 4 - 16% Industrial: 34 - 96% Domestic and other sources: 53 - 56%

Source: MoPNG 2002

There are limitations in the existing source apportionment studies in the country. In terms of particulate contribution from different sectors, not all possible sources of particulates have been consistently considered in all the studies. Currently air quality monitoring stations in the country monitors SPM and in a few locations RSPM, but the contribution of fine or ultrafine particles is not known.

Recently, the Mashelkar Committee commissioned a study on ambient air quality and source apportionment of RSPM (PM₁₀) in Kanpur city through the National Environment Engineering Research Institute (NEERI), Nagpur. The following broad conclusions were drawn from the study (MoPNG 2002):

- PM₁₀ contribution from auto exhaust in Kanpur city is about 16%
- 25%-40% of the PM₁₀ contribution is from industrial and other sources
- PM₁₀ contribution from diesel generating sets is high
- Around one-third of PM₁₀ contribution is from resuspended dust and of natural origin.

According to another study, PM_{10} emissions from the use of biomass fuels (when compared to other fuels) are found to be high in indoor environments where these fuels are used for domestic cooking (Kandlikar M and Ramachandran 2000).

A study in the U S has also suggested that 80%–90% of primary particulate emissions are fugitive dust with only a 3%–9% contribution from automotive exhaust emissions (CONCAWE 1999b). Another study in Eastern Germany revealed that ultrafine particles accounted for 73% of the particles per cm^3 of air even though their measured mass based concentration was approximately 1% (Panyacoist 2000). At the national level, there are indications from the National Air Quality Monitoring Programme (NAMP) data that RSPM in the country makes up one-third to two-third of TSP and $PM_{2.5}$ has been found to constitute about one-half of RSPM (TERI 2001).

Health costs of air pollution

On a global basis, estimates of mortality due to outdoor air pollution run from around 200,000 to 570,000, representing about 0.4%–1.1% of the total annual deaths (WRI 1998). Worldwide, WHO estimates that as many as 1.4 billion urban residents breathe air that exceeds WHO guidelines (WRI 1998). An assessment of health damages from exposure to the high levels of particulates in 126 cities worldwide where the annual mean levels exceed $50 \mu g/m^3$ reveals that these damages may amount to near 130,000 premature deaths; over 500,000 new cases of chronic bronchitis and many more lesser health effects each year (Lvovsky 1998). Each episode of illness caused by or made worse by air has direct and indirect economic consequences for individuals and society. They range from the costs of medical care through costs due to absence from work, to the loss of healthy years of life. Thousands of people have been exposed to the risk of chronic bronchitis and other respiratory diseases with varying degrees of inflictment.

The cost numbers show a significant loss on the GDP of a country due to the impacts of air pollution. Table 3.2 summarizes the economic loss due air pollution in a number of countries.

Table 3.2 Economic losses due to air pollution

Country	Externality costs due to air pollution	Year	Source
Austria	3.8% of GDP	1996	WHO 1999a
France	3.2% of GDP	1996	-do-
Switzerland	2.1% of GDP	1996	-do-
Hong Kong	0.51% of GDP	1996	http://www.gov.hk/epd/english/environmentinhk/air/studyreports/effect_econ_amb_ap.html
	0.35% of GDP	1996	-do-
China	5% of GDP	1998	http://www.earth-policy.org/Updates/Updates17.htm
China	12%(GDP/capita)	1998	Lvovsky 1998
India	9%(GDP/capita)	1998	Lvovsky 1998

The developed world

In the US, an estimated 80 million people live in areas that do not meet the US air quality standards, leading to 50,000 to 120,000 deaths annually and costing 50 billion dollars (WRI 1998). There have been a number of studies undertaken in Europe to determine the impact of car emissions on human health and the environment. In Europe, the 1999 WHO report on health costs due to road traffic-related air pollution revealed that long-term exposure to air pollution from cars in adults, caused an extra 21,000 premature deaths per year from respiratory or heart disease and caused 300,000 extra cases of bronchitis in children 15,000 hospital admissions for heart disease, 395,000 asthma attacks in adults and 162,000 attacks in children. A study conducted by the World Health Organisation on the human health impact from road related air pollution in countries like Austria, France and Switzerland suggested that traffic related pollution had significant impacts on the health costs (WHO 1999a). The estimated external public health costs of total air pollution and traffic related air pollution in this study are summarized in Table 3.3.

Table 3.3 Health costs due to PM10 emissions

Country	Year of study	Method of economic valuation	Health cost due to air pollution (million Euros)	Health cost due to transportation (million Euros)	Mortality cost due to air pollution (million Euros)	Morbidity cost due to air pollution (million Euros)
Austria	1996	WTP*	6700	2900	5000	1700
France	1996	WTP	38900	21600	28600	10400
Switzerland	1996	WTP	4200	2200	3000	1600

*Willingness to pay

Source: WHO 1999a

The developing world

The human cost of particulate air pollution in the developing world is staggering. In Latin America, about 81 million city residents i.e. more than one quarter of all city dwellers are exposed to high levels of air pollution resulting in 65 million days of illness each year (WRI 1998). In South Asia, acute respiratory illness deaths are reported to be as large as 1.4 million per year (UNEP 2002).

In terms of health impacts of air pollution, barring one or two studies there is very little epidemiological research in India, and one has to rely on back-of-the-envelope estimates. Further, studies on measuring health costs on account of vehicle emissions alone have not been made in India. Carter Brandon and Kirsten Homman for World Bank, for instance, conducted in 1995, a study on valuing the economy-wide cost of environmental degradation in India, covering besides air pollution, damage from water pollution, industrial hazardous waste, soil and rangeland degradation, deforestation, coastal and marine resources, loss of biodiversity, and decline in tourism. Brandon and Hommann (1995), for instance, extrapolated dose-response functions from developed countries to estimate mortality and morbidity due to ambient air quality exceeding World Health Organization (WHO) guidelines in 36 Indian cities. The pollutants they considered were PM, SO₂, NO_x, and lead. Ozone and indoor air pollution are not considered due to lack of data. They concluded that the annual health costs due to ambient air pollution levels ranged between 517 and 2,102 million dollars (about Rs 25 to Rs 100 billion). They also estimated that over 40,000 premature deaths would be avoided if pollutant levels in these cities were reduced to the WHO annual average standard. A study by TERI in 1998 which considered more sources of pollution and the entire country, including indoor pollution from rural areas, reveal that out of a total of 8.2 million deaths in India, in 1989, anywhere between 0.9 and 3.6 million could be attributed to particulate air pollution (TERI 1998). The study also estimates that 40% to 60% of pre-school children and 25% to 30% of women in the reproductive age suffer from chronic lung diseases. The annual loss in the country due to the adverse effects of air pollution on human health is estimated at 885 billion to 4250 billion rupees (TERI 2001).

Air pollution related health studies in India

Air pollution is primarily an urban phenomenon – except that indoor air pollution is largely rural – with the main pollutant of concern in most cities being PM. A study revealed around 500,000 premature deaths annually in India

is due to indoor air pollution alone (Smith 2000). Diseases related to air pollution in India are given in Annex 3.9.

A number of studies were conducted in the country regarding air pollution and its health impacts by various organizations/institutions which were compiled by the Central Pollution Control Board (CPCB 2001a). Some of these are summarised below.

The Vallabhbhai Patel Chest Institute, University of Delhi

The study was carried out in Delhi in 1997-98 and showed that exposure to particulate matter has a definite deleterious impact on respiratory health and contributes to total respiratory morbidity. Another study was conducted around the same time investigated the respiratory symptoms and lung functions of welders in Delhi. The general symptoms of these workers due to exposure during work were heaviness in chest, eye irritation, passage of black sputum, throat irritation, nasal irritation and nausea. Results showed that chronic bronchitis was diagnosed in 25% of the welders and was observed that longer duration of exposure led to greater chances of developing chronic bronchitis.

The All-India Institute of Medical Sciences, New Delhi

A study was conducted by AIIMS in late 1990s to correlate the daily levels of various pollutants with the number of patients visiting the casualty for aggravation of certain defined cardio-respiratory disorders. Results showed that ambient levels of pollutants exceeded the National Ambient Air Quality Standards on most of the days over a two year period. The emergency room visits for asthma, chronic obstructive pulmonary disease and acute coronary events increased by 21.3%, 24.9% and 24.3%, respectively, on account of higher levels of pollution. Another health based survey conducted by AIIMS on individuals in residential areas of Delhi pointed out that the most common symptoms related to air pollution were irritation of eyes (about 44.4% of the subjects surveyed suffered), cough (28% suffered), and pharyngitis (16.5%), dyspnoea (16% suffered), nausea (10% suffered) and respiratory problems (5.95% suffered). Results showed that in comparison with standard values for lung function, the residents of Delhi had lower lung functions.

The World Bank

The study showed that there is a positive and significant relationship that exists between particulate pollution and daily non-traumatic deaths and deaths due to respiratory and cardiovascular problems in Delhi. It was observed that the

impact of particulate matter in Delhi is less than that estimated in other countries. A possible reason as given in the study is that more deaths occur in Delhi due to infectious diseases and fewer occur due to cardiovascular and respiratory problems. The impact of particulate on cardiovascular and respiratory lower is smaller because diseases like pneumonia which have a weaker association with particulate matter, constitute larger fraction of respiratory deaths in Delhi.

Chittaranjan National Cancer Institute and Kolkata University

This joint study in 1998-2000 looked into the respiratory symptoms, and impairment in lung function in two sets of population urban and rural, in West Bengal. The study pointed out that there is a substantial increase in symptoms of both upper and lower respiratory tract diseases among the urban group. Respiratory symptoms were found to be more frequent in winter when pollution levels of the city with respect to RPM were highest. However the frequency of symptoms during monsoon was greater than that in summer despite the lowest RPM level. This could be because of a greater proliferation of micro-organisms as a result of higher humidity. The study clearly shows that chronic inhalation of the city's air causes a decline in lung function in a significant percentage of the inhabitants of the city. There was also direct relationship with the degree of exposure to urban air pollution. Individuals exposed to high levels of vehicular emission like traffic policemen, drivers, street hawkers, garage workers showed reduced lung functions compared to less exposed individuals (employees, housewives, students). (CPCB 2001a).

Air quality standards and monitoring

In India, the Central Pollution Control Board (CPCB) and the State Pollution Control Boards are the statutory authorities entrusted with the responsibility of implementing the Air (Prevention and Control of Pollution) Act 1981. The National Ambient Air Quality Standards (NAAQS) were first adopted under the Air Act and have set standards for criteria pollutants (see Annex 3.10). The primary aim of ambient standards is to provide a basis for protecting public health from the adverse effect of air pollution and to eliminate, or reduce to a minimum, the air pollutants that are hazardous to human health and well being. The standards are a derivation of the health-based guidelines set by the World Health Organization (WHO).

Annex 3.10 provides a comparison of the NAAQs with WHO guidelines and the standards prevailing in US, UK, and Japan. Regular monitoring of criteria

pollutants began in 1967 by the National Environmental Engineering Research Institute (NEERI) under the NAMP (National Air quality Monitoring Programme) ambient programme. Gradually monitoring has been expanded and currently there are 290 monitoring stations – 30 stations are managed by NEERI, and other 260 stations are managed by CPCB (CPCB 2000a). Of the total, only 204 stations are currently operating. RSPM or PM₁₀ monitoring has been included in 20 cities since 2000 apart from the regular monitoring of SPM at all the existing monitoring stations.

Air quality status in Indian cities

The CPCB monitors the ambient air quality in almost all major cities in the country directly or through the State Pollution Control Boards, universities and other institutions. The air quality parameters regularly monitored covering 90 cities are SPM, SO₂ and NO_x. Other pollutants such as CO, PAH, O₃, RSPM, benzene and trace metals are also monitored in Delhi and some other cities, but not in all cities.

Figures 3.1 and 3.2 show the annual concentrations of SPM and NO_x from 1995 to 2001 based on CPCB monitored data in metropolitan cities. The following observations stand out.

- In most cities, the SPM levels exceeded the annual permissible standard of 140 micrograms per cubic metre in residential areas, and the majority of cities experienced critical levels. In 2001 as compared to 1995, there was a reduction in SPM in a number of large sized cities. This could have been because of improved enforcement of measures for air quality and the growing awareness among industries of the use of emission control devices.
- overall the level of NO_x was within the annual permissible standard of 60 microgram per cubic metre in residential areas. The decline in NO_x levels of many cities could have been a result of the enforcement of vehicular pollution control strategies in the country.

The mix and growth of any city's motor vehicle population determines the contribution of vehicular emissions to the overall pollution there. Pollutants in the ambient air originate from many sources, of which automobiles are one. The contribution of automobile exhaust to the levels of different pollutants requires detailed studies. The Expert Committee on Auto Fuel Policy analysed the air quality status in different cities and carried out an extensive review of literature to estimate the contribution of automobile emissions to the air pollution load (MoPNG 2002).

Figure 3.1 Average of annual mean concentration of SPM at air quality monitoring stations in residential areas (micrograms per cubic metre)

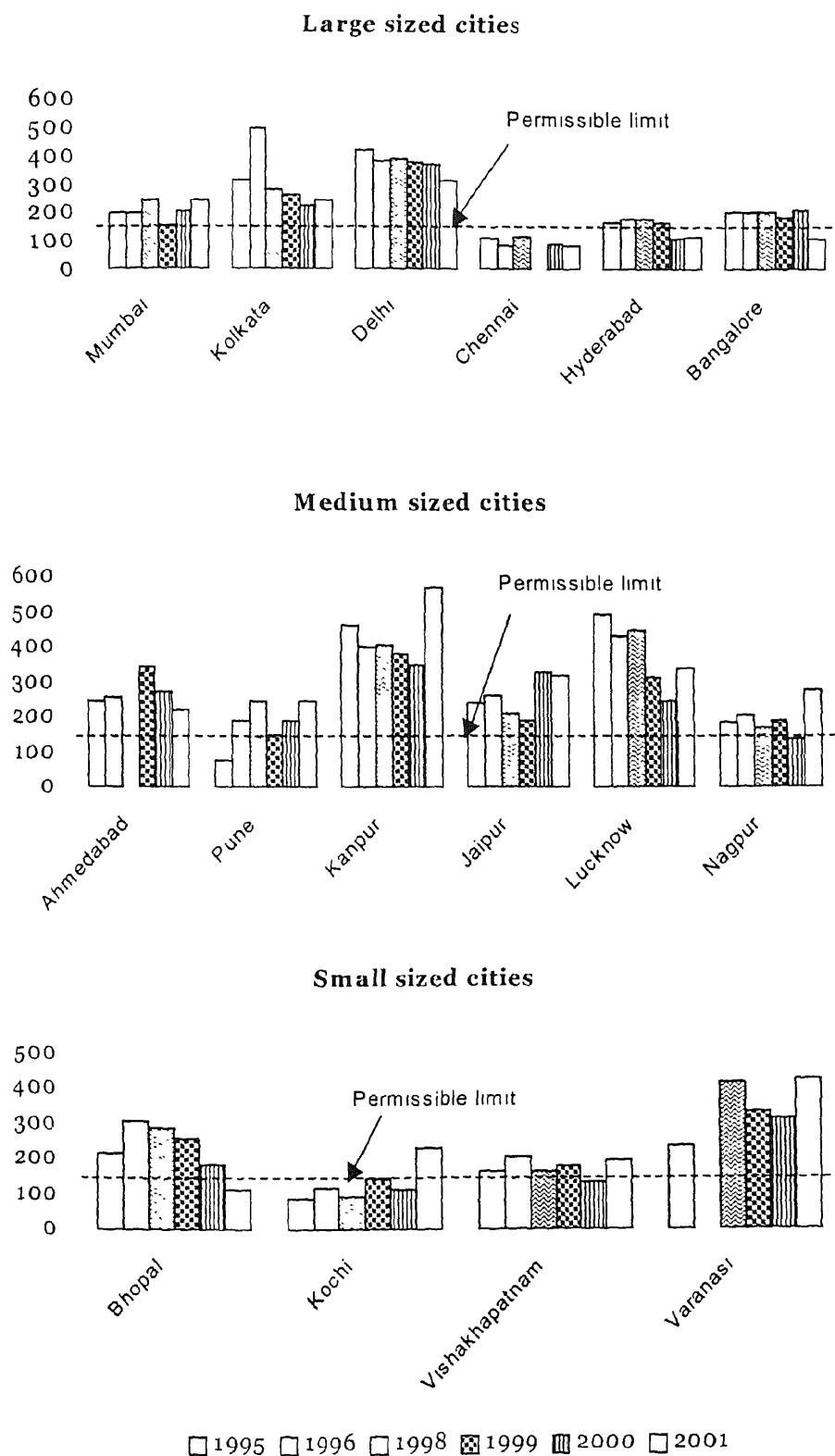
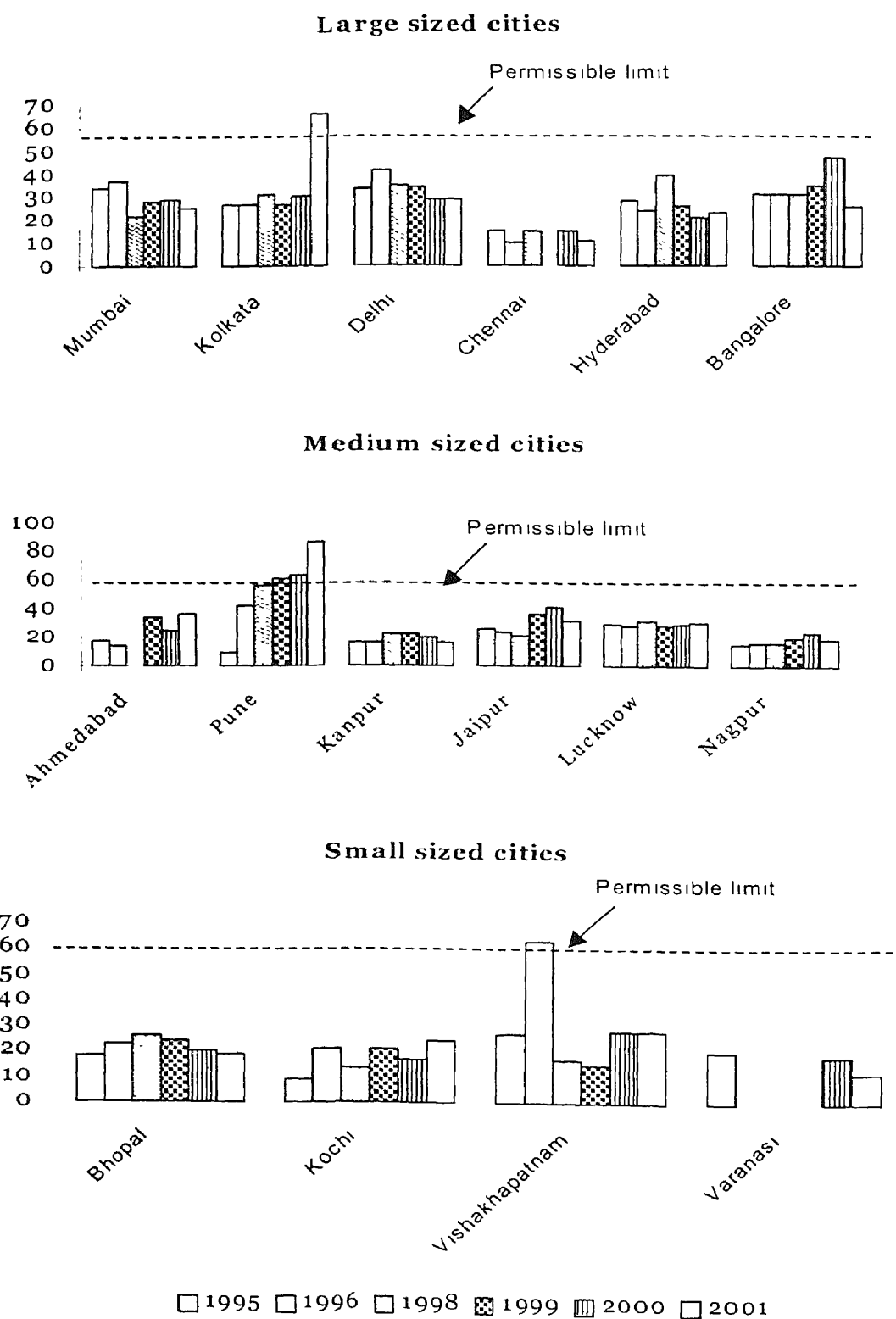


Figure 3.2 Average of annual mean concentration of NO_x at air quality monitoring stations in residential areas (micrograms per metre cube)



The Expert Committee came up with the following conclusions.

- No direct relationship can be established between ambient air quality change and growth pattern of automobiles in most cities. Therefore, to assess the contribution of automobiles to the overall air pollution load, air pollution source inventories are necessary.
- Although the changes made in the auto fuel quality and the vehicular emission norms in all major cities—except in the National Capital Territory of Delhi, Mumbai, Kolkata and Chennai, where certain advance actions have been taken—were the same, no two cities show the same trend with time in the observed pollutant concentrations.
- The RSPM expressed as a percentage of SPM varies substantially from city to city. RSPM is noted to be as low as 22% of the SPM concentration in Varanasi and as high as 90% in Ahmedabad. There appears to be, thus, no direct relation in the RSPM concentration with the vehicle population in different cities in the same year or in the same city in different years. There has been a reduction in RSPM concentration in 2001 compared to 2000 in the residential areas of cities of Bangalore, Delhi, Hyderabad, Jaipur, Kolkata, Lucknow, Mumbai and Nagpur. In the cities of Ahmedabad, Chennai, Kanpur, the concentration was almost the same for both the years. Pune showed an increase in RSPM concentration during 2001 compared to that in 2000.

Transport fuels and their harmful effects

Conventional automobile engines are spark ignition (SI) or compression ignition (CI) powered by petrol and diesel, respectively. While petrol and diesel are long-chain HCs with a larger number of carbon atoms bonded to hydrogen atoms in the chain, alternative gaseous fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG) which are used in SI engines belong to the group of short-chain HCs with fewer carbon atoms; their lower C:H ratio renders them less polluting. The C:H ratio together with the effects of fuel characteristics, fuel additives, driving cycle, emission control devices equipped in the tailpipe of vehicles and secondary pollutants generated in atmospheric reactions all contribute to air pollution and its effect on health. Fuels that have less carbon in them also have less energy, and therefore more fuel is required to do the same work.

While the environmental impact of PM and NO_x emissions from diesel engines is higher compared to that of petrol emissions, CNG and LPG engines of similar size, the emissions of CO and HC are higher from petrol, CNG and LPG

compared to a diesel engine. All over the world, initiatives have been taken to improve the quality of liquid fuels and make use of less polluting short-chain hydrocarbon fuels such as CNG and LPG, to reduce tailpipe exhaust emissions. Improvements in fuel quality are achieved through the removal or reduction of fuel constituents such as sulphur and PAH in diesel, and sulphur, lead, benzene and other aromatics in petrol (see Chapter 5 for details). Further emissions reductions are obtained by improving engine technology and introduction of fitment of emission control devices (see Chapter 7 for details).

Petrol

The major pollutants from petrol-fuelled vehicles are CO, HC, lead (only for leaded petrol) and to some extent NO_x. For a given fuel quality, emissions of these pollutants are influenced by factors such as the air: fuel ratio at the time of combustion, ignition timing and a number of engine parameters and also the use of emission control devices. Higher ratios in terms of the air-petrol mixture (or the lean burn engines) produce less HC and CO emissions. Light-duty petrol vehicles not equipped with pollution control devices have high exhaust emissions during the acceleration followed by the deceleration, cruising and idling cycles. Thus frequent cycle changes as required in congested urban areas, increase pollutant emissions. At higher cruising speeds HC and CO emissions decrease, but NO_x increases. As elaborated in Chapter 7, three way catalytic converters installed on petrol vehicles are said to reduce CO and HC emissions by 90% and NO_x emissions by 70 % (World Bank 1997a). Evaporative emissions also release HC vapours directly into the atmosphere mainly from the fuel tank and carburettor. According to an emissions study in the US, the estimates of the product proportions of hydrocarbons emitted from US petrol (with a benzene content of 1%–1.5%) were benzene (77%), acetaldehyde (6%), formaldehyde (11%), and butadiene (6%) (Guibet 1999). Particulate lead is released from petrol fuels that use lead additives. There has been a mandate in the country to use unleaded petrol since February 2000 to reduce particulate lead in ambient air.

Diesel

Diesel engines operate at high air: fuel ratios and hence have lower HC and CO emissions but have higher particulate emissions compared to petrol vehicles. It is well known that the most serious health risks arise from the exposure to diesel particulates which are small in size and respirable and consist of a solid carbonaceous matter along with various other compounds such as unburnt hydrocarbons, polycyclic aromatic hydrocarbons, residue of lubricating oil

additives, reaction products of SO_2 and NO_2 , and sulphuric acid. Most of these air toxics emitted from uncontrolled diesel vehicles are highly concentrated in the fine particle fraction.

Studies have shown that particulate toxic pollutants from diesel exhaust can enhance allergic inflammation and induce allergic immune responses (NCER 2003). Recent report by the USEPA suggest that diesel particulates are likely to be and not highly carcinogenic as previously stated. The latest health assessment document by the USEPA states that long term exposure to diesel exhaust is likely to be a lung carcinogen to humans, as well as have non cancer effects on the respiratory system. The non-cancer effects were similar to those seen with exposure to ambient particulate matter specifically $\text{PM}_{2.5}$ (EPA 2002). However, the recent assessments made in this context did not provide a cancer potency value due to insufficient data. The assessment did provide the range of possibilities of lung cancer risk from environmental exposure to diesel (EPA 2002). There are numerous studies that point out the transportation sector as contributing significantly to air toxics (NATA 1998).

Although the contribution of transport fuels to atmospheric SO_2 levels is generally small, there is considerable interest world wide to reduce the sulphur in diesel fuel. In the combustion process sulphur compounds burn to form acidic products (SO_2 , SO_3). Sulphuric acid (H_2SO_4) is formed, often called sulphate in the industry, which along with water and HCs increases the burden of PM in the exhaust. Thus, the higher the sulphur content in diesel the higher the PM formation. The motivation for reducing sulphur level in diesel is related to reduction of PM emissions.

Sulphur in diesel fuel also renders modern particle filters and oxidation catalysts—designed to reduce emissions of PM, NO_x , HC and CO—inoperable or reduces their performance and longevity (Clean Technologies Information Pool 2002). Since diesel engines are used for medium and heavy vehicles due to their long life and high fuel efficiency, continuous efforts are on to improve traditional diesel vehicles both by the introduction of cleaner diesel fuels (with a lower sulphur content) as well as by the introduction of better automotive technologies to reduce particulate and other emissions.

There is a general agreement in the literature that even with advances in engine technology and emission control devices, ultra-low sulphur diesel (ULSD) containing upto 50 ppm sulphur content in diesel would be necessary to reduce emissions of ultra-fine particulates from diesel vehicles to environmentally acceptable levels (see Chapter 7 for further details). {Diesel fuel containing 10 ppm or less is called sulphur free diesel (CFSFS 2000)}. The

sulphur content of Indian diesel has been gradually been decreased and currently is 0.05% (CPCB 2000b; MoPNG 2002). The details on low sulphur diesel are provided in Chapter 4.

However, it is important and necessary to ensure that ULSD is not adulterated with low quality diesel or other adulterants. Currently, ULSD is not produced or sold in India. However, it can be imported or produced in the country by upgrading existing Indian refineries. Many European countries, particularly those in northern and western Europe, are already committed to ULSD, which contains 0.005% or 50 ppm sulphur. ULSD, commonly known as city diesel in Europe, was introduced in Finland and Sweden in 1993; since then it has captured 100% of the Scandinavian and UK diesel markets. ULSD is also commercially available in the US but in limited areas, mostly in California and the north-eastern states of Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, and Maryland. Texas and the mid-western states (Ohio, Indiana, and Illinois) will now also have ULSD. ULSD has also been introduced in Hong Kong and in the Tokyo metropolitan district.

Gaseous fuels

Although gaseous fuels (CNG and LPG), is known to be less polluting in terms of PM and NO_x compared to traditional vehicular fuels, emissions of HCs and CO are observed to be high (CFSFS 2000). Further, it is important to note that there is no gas engine that has the same kind of power output, fuel economy, and reliability as that of a modern diesel engine.

In the new generation cars, there may be some improvement in emissions of CO by changing over to gaseous fuels but there is no particular trend with regard to other regulated pollutants. As compared to petrol, LPG showed higher NO_x while use of CNG showed marginally higher particulates. According to a World Bank briefing note on international experience with CNG vehicles, with respect to emissions, it is worth noting that advanced technology petrol cars with three-way catalysts are so clean that the fuel itself (that is, whether liquid or gas) plays a relatively minor role, especially for regulated emissions. Under these circumstances, converting an advanced petrol vehicle to gaseous fuel could even increase, rather than decrease emissions (MoPNG 2002).

The conversion to gaseous fuel engines (CNG or LPG) for heavy duty applications (like buses) involves a changeover to SI operation. Engine manufacturers use either stoichiometric or lean burn combustion. For in-use diesel buses, the conversion techniques currently being used in India are not proven technologies. As reported by the Mashelkar Committee 'for conversion,

of the existing diesel engine, it is modified to run on CNG by replacing the piston, cylinder head, cooling system, intake manifold and incorporation of an ignition system and converting it into an SI engine'. It is not a reliable system and there are complaints of engine overheating, spark plug fouling, engine head leaking, etc. The OEM CNG engines in India are also not original gas engines, but converted from diesel engines using the diesel engine block (MoPNG 2002).

Though CNG-fuelled engines are considered as a green fuel alternative to conventional diesel engines (Holmen and Ayala 2002), the effectiveness of CNG as a fuel would require emission control technologies such as particulate filters/traps and oxidation catalysts to minimize every possible emission.

Conclusions

Urbanization has had a huge impact on the growing air pollution levels in Indian cities. Increased awareness and importance of the issue is brought about by the fact that there are growing concerns among the stakeholders.

The levels of criteria pollutants measured and reported in major Indian cities show that particulates are pollutants of concern. However their sources, contribution to pollution levels and the interaction of particulates on health endpoints are complex.

Most epidemiological studies have looked into the associations of mortality and morbidity endpoints of air pollution and have often associated with particulates in air. Studies have shown strong evidence of particulates to cause respiratory illness, and to a lesser extent to morbidity like asthma and cardio respiratory illnesses. Other individual pollutants have also been linked with observed association with specific health impacts, but in general, it has been difficult to identify causes, by epidemiology because people are exposed to a mix of pollutants and the different pollutants tend to be correlated with each other.

In terms of contribution of the transportation sector to pollution levels in the country, comprehensive emission inventories are limited and mostly done in a few select cities of India. There is also a discrepancy in terms of the emission factors. The transportation sector in general contributes to emissions of CO, HCs, NO_x and other unregulated toxic pollutants and specifically ultrafine particles. Existing studies point out that this sector contributes significantly NO_x and CO levels. In terms of particulates, there are large uncertainties about the source contributions to total ambient particulates more so with small particles.

To pinpoint the magnitude of the health effect from air pollutants from the transportation sector, there needs to be more research on health effects of

vehicular pollutants in the country. There is also a need for more emission inventories and source apportionment studies to see the contribution of transportation sector to pollutants specifically to respirable and ultrafine particulates. This calls for strengthening of the existing monitoring systems to monitor RSPM and small particles.

However in terms of reduction of air pollution levels in the country various independent measures are needed. Measures such as better maintenance of existing vehicles, phasing out of old vehicles along with the introduction of cleaner fuels and technologies can play a vital role in reducing emissions from the transportation sector.



Environmental regulations for motor vehicles

Introduction

In the last few decades, the production of motor vehicles has grown phenomenally. The number of new vehicles produced each year worldwide has risen from about 5 million just after the Second World War to nearly 55 million in 2001. With a growth in GDP and population, the world's vehicle fleet is likely to increase rapidly, especially in the rapidly industrializing countries of Asia. The resultant growth in vehicle emissions is of great concern to governments as they strive to protect public health and welfare.

Each country has drawn its own vehicle emission standards and matching fuel quality specifications, which the engine manufacturers and oil companies have to meet in their production of vehicles and fuels respectively. To ensure progressively stringent emission norms, it becomes imperative that fuel specifications and improved engine technologies are necessary. The interdependence of engines and fuels has resulted in three major auto oil programmes: (1) the EPEFE (European Programme on Emission Fuels and Engines), (2) the US AQIRP (Air Quality Improvement Research Programme), and (3) Japan Clean Air Programme. In the late 60s and early 1970s the first steps towards controlling vehicular pollution being taken in the European Union, US, and Japan. In India, emission norms for new vehicles were first notified in the early 90s.

The European Union

Historically, the EC's legislative programme on vehicle emissions has concentrated on new vehicle standards for a limited range of pollutants (carbon monoxide, hydrocarbons, nitrogen oxides, and smoke/particulates) for different categories of vehicles (see Annex 4.1 for details).

The first petrol emissions legislation came into effect in 1971; it has since been revised with stricter norms being imposed each time, no less than 13 times (Hosier 2000). Such revisions were essentially arbitrary. Diesel emission standards were introduced in Europe only in the late 1980s, primarily because the usage of diesel was low until the early 1980s (<7% across Europe), but grew rapidly to 15% by 1985. Currently, the market share of diesel passenger cars in

Europe is about 35% and is likely to go up to 50% by 2005 (Kang 2003). The diesel standards too have been amended for increased stringency, more than seven times (Hosier 2000).

Stricter emission norms meant that additional emissions hardware and control software were also needed. For example, petrol fuel injection and catalysts were first introduced in the late 1980s. Three-way catalysts were required to meet the standards for CO and HC+NO_x emissions and electronic fuel injection was necessary for precise air/fuel control to support the catalyst's operation. Evaporative emission testing was introduced with the Euro I (1992) standards. Vehicle tailpipe emissions were already at a low level.

Auto-oil programme

Euro II legislation established a scientific programme called the Auto-Oil Programme to identify future air quality requirements and the measures necessary to meet them. This initiative which started in 1992 was wide reaching and involved legislators, the European Parliament, academia, consumer groups, the oil industry, and the automotive manufacturers. Its aim was to set vehicle and fuel standards for the period 2000-2010. The Programme was comprehensive and adopted a rational approach to future automotive emissions and air quality legislation. The programme was designed to identify the obstacles to achieving the air quality targets and to offer the most cost-effective solutions by the following means:

- Assess vehicle/fuel technology interaction with emissions. Review what is already understood, and then conduct a research programme to fill gaps in the knowledge base.
- Develop a comprehensive emissions inventory.
- Model air quality and compare with possible future standards.
- Build into that model the effects of both, currently planned measures and possible future options for legislation.
- Review the cost effectiveness of potential remedial action.

The European Programme on Emissions, Fuels and Engines (EPEFE) an initiative of the EU Commission reviewed available data and designed projects to extend the knowledge base. A series of programs were carried out, managed by the automotive industry (ACEA) and the European oil industry (EUROPIA). Fuel matrices were designed to study the effect of variations in the sulphur content, mid-range distillation and aromatics content of petrol and the cetane number, polyaromatics, density and back-end distillation of diesel fuel. Test

vehicles/engines were selected to reflect the wide range of models found in Europe. They were equipped with prototype engine technologies then under development, which improved upon the requirements of the 1995/96 European emissions legislation. The EPEFE considered all classes of vehicles and the contributions of improved fuel inspection and maintenance programmes and the benefits of local measures, such as alternative fuel vehicles, for identified emission hot spots.

An air quality monitoring exercise was also coordinated by the European Commission by involving relevant experts in the field. It relied on regional and individual base inventories for a number of cities, compiled in 1990. Thereafter accredited emissions forecasting tools were employed to predict future air quality levels. The models had the ability to accommodate detailed breakdowns by both stationary and mobile emission sources and incorporate the effects on emissions of enhanced vehicle technology, modified fuels, non-technical measures such as traffic management and fiscal policies, inspection and maintenance and the use of alternative fuels.

In 1996, the Commission put forward a number of measures and proposals before the Council of European Union and the European Parliament arising from the Auto-Oil Programme's report. Auto-Oil I led to the adoption of a series of directives regulating emissions of certain pollutants from light-duty vehicles and the quality of petrol and diesel. These were joined subsequently by further proposals concerning emissions from other types of vehicles and improved procedures for inspection and maintenance.

At the end of the Auto-Oil I process, the Euro III/IV proposals on emission limits were drafted for passenger cars and light duty vehicles and for heavy-duty vehicles and fuel quality specifications. These proposals were subjected to over two years of political debate and the resulting directives were finally published in December 1998. Euro III legislation for new passenger cars and light trucks came into effect from 1 January 2000 with the mandatory registration date one year later. Euro IV becomes mandatory in 2005, starting with passenger cars and small light trucks.

In Auto-Oil II the approach was to identify environmental objectives for air quality; forecast future emissions and air quality; establish emission reduction targets (or appropriate functional relationships); collect input data on costs and effects of potential measures to reduce emissions; and carry out a cost effectiveness assessment as the basis for a future air quality strategy.

Auto-Oil II involved the estimation of future emissions from road transport and other sources and future air quality and led to a series of conclusions and

recommendations on emission reduction measures to be taken in the road transport sector. Auto-Oil II has shown that emissions from road transport of the main regulated pollutants can be expected to fall to less than 20% of their 1995 levels by 2020, although the results for particulate matter cover only diesel emissions. By contrast, CO₂ emissions are expected to continue rising until 2005, before stabilising on the assumption that the voluntary commitments of the car manufacturers are met. These emission reductions are expected in spite of the forecast growth in transport demand.

The results of the recent Auto-Oil II programme have revealed two specific air quality problems, which will need to be major priorities for the next phase of the EU's air quality policy. These relate in particular to particulate matter and ozone.

Low sulphur fuels

It has become increasingly clear, as emissions regulations have become more stringent, that fuel properties and vehicle technologies are closely intertwined. Fuel parameters such as lead or sulphur content must be controlled as a precondition to introducing advanced vehicle technologies. In addition, many other fuel properties, such as aromatic content and Reid Vapour Pressure, must also be controlled to enable maximum emissions reduction at the lowest cost. The European Union has passed a law requiring far lower amounts of sulphur in petrol and diesel (50 parts per million (PPM) maximum) by 2005, with a total phase in of sulphur free fuels by 2009. The final approval of the law follows years of debate by EU lawmakers on the timetable for making cleaner fuels more widely available, in an attempt to reduce air pollution. The European Parliament voted on 30 January 2003 to set a deadline of 1 January 2009, for an EU changeover to zero sulphur petrol and diesel fuels in road transport, and the Council of Ministers approved the measure on 7 February 2003.

The Kyoto Agreement

Under the Kyoto Agreement, the European Union has agreed to limit the emissions of greenhouse gases. In order to do this, the EU adopted a strategy on reducing CO₂ emissions from new passenger cars in 1996. As part of this strategy, the Commission has made a voluntary agreement with the European automobile manufacturer. The industry has committed itself to reducing average CO₂ emissions from new passenger cars by 25 % over the next decade, setting a target of 120 g/km to be attained by 2005 (2010 at the latest).

The United States

In July of 1970, the US Congress adopted the first major Clean Air Act, and established the United States Environmental Protection Agency (USEPA). It gave the new Agency, broad responsibility for regulating motor vehicle pollution. The Clean Air Law called for a 90 percent reduction in automotive emissions. The law also directed EPA to set health-based National Ambient Air Quality Standards for six pollutants, all of which are present in auto emissions to some degree. These pollutants are called criteria air pollutants because the agency has regulated them by first developing health-based criteria (science-based guidelines) as the basis for setting permissible levels. One set of limits (primary standard) protects health; another set of limits (secondary standard) is intended to prevent environmental and property damage. The criteria pollutants are CO, Pb, NO₂, O₃, PM, and SO₂. A geographic area that meets or does better than the primary standard is called an attainment area; areas that don't meet the primary standard are called non-attainment areas. EPA and state governors have cooperated to identify non-attainment areas for each criteria air pollutant. The EPA has classified the non-attainment areas according to how badly polluted the areas are.

The Clean Air Act, 1970

The Clean Air Act (1970) is a federal law, which covers the entire country, but the states do much of the work required to enforce the Act. For example, a state air pollution agency holds a hearing on a permit application by a power or chemical plant or fines a company for violating air pollution limits. Under this law, the EPA sets limits on the levels of a pollutant that can be present in the air anywhere in the United States. The law allows individual states to have stricter control standards but states are not allowed to have less strict pollution controls than those set for the whole country.

State implementation plans

States are required to develop state implementation plans (SIPs) that explain how each state will do its job under the Clean Air Act. A state implementation plan is a collection of the regulations a state will use to clean up polluted areas. The states have to involve the public, through hearings and opportunities to comment, in the development of each state implementation plan. The EPA must approve each SIP, and if a SIP isn't acceptable, the EPA can take over enforcing the Clean Air Act in that state. The United States government, through the EPA,

assists the states by providing scientific research, expert studies, engineering designs and money to support clean air programmes.

Transport and air quality

US EPA's Office of Transportation and Air Quality (OTAQ) is responsible for protecting public health and the environment. EPA standards dictate how much pollution autos may emit but automakers decide how to achieve the pollution limits.

There have been a variety of approaches that have been adopted by the EPA. From better engine design to better transit options, programmes to reduce mobile source pollution have attempted to address not only vehicles, engines, and equipment, but also the fuels they use and the people who operate them. Technological advances in vehicle and engine design, together with cleaner, higher-quality fuels, have reduced emissions so much that EPA expects the progress to continue, even as people drive more miles and use more powerful engines. EPA studies show that today's cars emit 75 to 90 percent less pollution (for each mile driven) than their 1970 counterparts, thanks largely to advancements in vehicle and fuel technology.

The Clean Air Act (1970) required new cars to meet a 0.41 gram of hydrocarbons per mile standard and a 3.4 grams of carbon monoxide per mile standard by 1975; nitrogen oxide emissions were to be reduced to 0.4 grams per mile by 1976 (the nitrogen oxide standard was later revised in 1977). In 1974, the Energy Policy Conservation Act was adopted by the Congress setting the first fuel economy goals. The Corporate Average Fuel Economy (CAFE) programme established a phase-in of more stringent fuel economy standards beginning with 1975 model vehicles.

In 1975, first generation catalytic converters in 1975 were introduced which significantly reduced hydrocarbon (HC) and carbon monoxide (CO) emissions. Since lead inactivates the catalyst, 1975 saw the widespread introduction of unleaded petrol. This resulted in dramatic reductions in ambient lead levels and alleviated many serious environmental and human health concerns associated with lead pollution

(<http://www.epa.gov/otaa/inventory/overview/solutions/milestones.htm> as on September 02, 2002).

Clean Air Act, 1977 Amendment

In 1977, the Clean Air Act was amended at the behest of automakers. The HC standards were delayed till 1980 and CO and NO_x standards were delayed until 1981. The nitrogen oxides standard was further relaxed to 1 gram per mile. The next major milestone in vehicle emission control technology came in 1980-81. In response to tighter standards, manufacturers equipped new cars with even more sophisticated emission control systems. These systems generally included a three-way catalyst (which converts carbon monoxide and hydrocarbons to carbon dioxide and water, and also helped reduce nitrogen oxides to elemental nitrogen and oxygen), plus an on-board computer and oxygen sensor. This equipment helped in optimising the efficiency of the catalytic converter.

In 1983, Inspection and Maintenance (I/M) programme were established in areas where air pollution was a concern. The programme required passenger vehicles to undergo periodic testing of the emission control systems. The EPA adopted stringent emission standards for diesel powered trucks and buses to take effect in 1991 and 1994.

Despite considerable progress, the overall goal of clean and healthy air was not met. The level of air pollution was still critical in virtually every major city in the United States. This was largely because development and urban sprawl created new sources of pollution and contributed to a doubling of vehicle travel since 1970. Hence it was felt that further emission reductions were essential to further progress toward clean and healthy air for everyone.

Clean Air Act, 1990 Amendment

In view of the issues highlighted above, the Clean Air Act for the first time since 1977, was amended and updated in 1990. The amended Act further required reductions in hydrocarbons, carbon monoxide, nitrogen oxides, and particulate emissions. The amendments also introduce lower tailpipe standards; more stringent emission testing procedures; expanded I/M programmes; new vehicle technologies and clean fuels programmes; and provisions for transportation management. The tighter tailpipe emission standards began to take effect with 1994 models. A comprehensive approach was taken to reduce the criteria air pollutants by the 1990 Act covering many different sources and a variety of clean-up methods. Many of the smog clean-up requirements involve motor vehicles (cars, trucks, buses). The carbon monoxide (CO) and respirable particulate matter (PM₁₀) clean-up plans are also set up like the plan for smog.

The 1990 Law also introduced several entirely new concepts with regard to reducing motor vehicle-related air pollution. For the first time, fuel was

considered along with vehicle technology as a potential source of emission reductions and more attention was focused on reducing the growth in vehicle travel. The act mandated that improved petrol formulations be sold in some polluted cities to reduce emissions of carbon monoxide or ozone-forming hydrocarbons. Reformulated petrol (which is designed to reduce emissions of volatile organic compounds and toxic air pollutants) was required to be sold in the nine worst areas that did not meet the minimum national air quality standards for ozone. This programme began in 1995 in ten metropolitan areas with severe smog problems. In areas where wintertime carbon monoxide pollution was significant, refiners had to sell oxyfuel, petrol with oxygen added, to make the fuel burn more efficiently. Other programme set high vehicle emission standards to stimulate the introduction of even cleaner cars and fuels. The Act also encourages the development and sale of alternative fuels such as alcohols, liquefied petroleum gas, and natural gas.

The 1990 Clean Air Act provides economic incentives for cleaning up pollution. For instance, petrol refiners can get credits if they produce cleaner petrol than required, and they can use those credits when their petrol doesn't quite meet clean-up requirements.

Tier 1 and 2 standards

For cars and light duty vehicles, two sets of standards, Tier 1 and 2, have been defined in the Clean Air Act. Tier 1 regulations were fully implemented in 1997. Tier 2 standards were adopted on December 21, 1999, to be phased-in beginning in 2004. The Tier 2 standards bring significant emission reductions relative to the Tier 1 regulation. Under the Tier 2 standard, the same emission standards apply to all vehicle weight categories under cars and light duty vehicles. Further, the emission limits that apply to all vehicles are fuel neutral. That is, vehicles fueled by petrol, diesel, or alternative fuels all must meet the same standards. In case of heavy-duty vehicles, emission standards for NO_x and PM have become very stringent over time. For instance, the emission standards for model year 2007 are 0.01 g/bhp-hr and 0.2 g/bhp-hr for PM and NO_x respectively, a reduction of around 97% – 98% over the 1990 emission standards. Annex 4.2 provides the Tier 1 and 2 standards for different categories of vehicles. Various programmes that have been introduced are elaborated below.

The California Pilot Programme

The California Air Resources Board (ARB) is the state agency responsible for protecting public health and the environment from the harmful effects of air

pollution. The ARB works in cooperation with the districts and the USEPA on strategies to attain state and federal ambient air quality standards and reduce toxic air emissions.

In 1996, the phase-in of the pilot programme in California started. Under this program, lower hydrocarbon emission standards (relative to cars in the general U.S. market) were set for a set number of new passenger cars and light trucks sold in California beginning in 1996. The standards were to drop still lower beginning in 2001, when a new nitrogen oxide standard also took effect. The sales requirement was 150,000 vehicles per year in 1996 through 1998 and 300,000 vehicles per year thereafter. California was given the option of mandating the availability of any fuel, which was considered necessary to operate clean-fuelled vehicles. Other states are allowed to adopt California's vehicle standards. Massachusetts, New York, Vermont, and Maine have adopted California emission standards beginning in the 1999, 1999, 2000 and 2001 model years, respectively.

California's air quality programme has achieved substantial progress over the past decades. In the Los Angeles area, the average levels of inhalable particulate matter (PM₁₀) fell by over twenty percent from 1988 to 2000 (<http://www.arb.ca.gov/planning/plan01/draft01.doc> as on September 02, 2002).

In February 2000, the California ARB adopted a new regulation to reduce emissions of NO_x and PM from urban transit buses. Under this regulation fleet operators have to choose between a diesel path and an alternative fuel path for their future bus procurements. The alternative fuel path requires that 85% of buses purchased or leased each year through model year 2015 are fuelled by alternative fuels. Transit operators who stay on the diesel path can purchase diesel fuelled buses, but are required to follow a more aggressive emission reduction schedule. When the regulation is fully implemented, buses on both paths will produce the same near-zero emission levels.

Clean-Fuel Fleet Vehicle Program

This provision applies to fleets in 23 metropolitan areas around the country that have high ozone and/or carbon monoxide pollution. This programme requires that a certain proportion of the new vehicles sold must meet lower emission standards. A certain proportion of new cars, light trucks, and medium-duty trucks purchased will need to meet the lower hydrocarbon and nitrogen oxide emission standards beginning in 1998. Individual states must ensure that appropriate fuels are available for clean-fuelled fleet vehicles. It is expected that

this programme would affect approximately 35,000 vehicles and result in about one million clean-fuelled vehicles by 2010. Eighteen areas have opted out of the Clean Fuel Fleet Program while four areas have adopted it.

National Low Emission Vehicles Program

In 1998, an agreement was reached between the Clinton administration, the automotive industry and the Northeastern states of the US to put cleaner cars on the road before they could be mandated under the Clean Air Act. The new cars are called National Low Emission Vehicles (NLEV). The NLEVs have been made available across the US since 2001.

The National Low Emission Vehicle Program (NLEV) is a voluntary program to introduce cleaner cars and light trucks in all parts of the country. Under the agreement between the States and automobile manufacturers, manufacturers began selling cleaner cars and trucks in a number of districts. Twenty-four of the largest automobile manufacturers have voluntarily entered into the NLEV program in the 45 states nationwide, which are participating in the programme.

Although the automobile manufacturers volunteered for the program, the lower emission levels and other requirements of the NLEV program are enforceable like any other federal new vehicle program. The NLEV program will continue to exist until the cleaner Federal emission standards become effective in the 2004 model year.

The National LEV program harmonizes the federal and California motor vehicle standards. The program is phased-in through schedules that require car manufacturers to certify a percentage of their vehicle fleets to increasingly cleaner standards.

Japan

Emission control in Japan started in 1966 when simple CO limits were introduced for ordinary-sized and small-sized motor vehicles fuelled by petrol, but the first long-term plan was established in 1970 by the Ministry of Transport (MOT). This plan proposed limits for CO, HC and NO_x from 1973. In 1971, the Central Council for Environmental Pollution Control (CCEPC) recommended that legislation should follow the US Muskie proposal and submitted recommendations for far more stringent exhaust emission standards. This led to tough limits being introduced in 1975, which required the use of catalysts in petrol cars. These limits (with a NO_x reduction in 1978) have not changed since then, but revisions to the test procedures have effectively made them more severe. Emissions limits for trucks, both petrol and diesel were also introduced

in 1974/5, but these limits have been tightened by varying degrees over the intervening years.

At present, carbon monoxide, hydrocarbons, and nitrogen oxides are regulated for motor vehicles fuelled by petrol or LPG (petrol/LPG motor vehicles). In case of diesel-powered motor vehicles, in addition to these three, particulate matter and diesel smoke is also regulated.

Air Pollution Control Law

In Japan, the maximum permissible limits for exhaust gases from motor vehicles are established by the Directorate General of the Environment Agency (EA) as prescribed by the Air Pollution Control Law (1968) and are adopted by the Ministry of Transport (MOT). In addition, EA also establishes the maximum permissible limits on the quality of automobile fuel and on the quantity of substances in automobile fuel, which are necessary to prevent air pollution caused by automobile exhaust gases. The MOT sets the emission targets on reduction rates based on recommendations by the CCEPC, an advisory body of the Ministry of Environment.

In December 1989, the CCEPC recommended new emission limits with both short-term (relating to diesel motor vehicles and fuel evaporative emission reduction for the petrol motor vehicles) and long-term targets (relating to LPG motor vehicles, off-road vehicles and two-wheeled motor vehicles) (<http://www.env.go.jp/en/pol/mv/policy.html> as on September 5, 02). Their aim was to set up the most stringent standards, which were technologically feasible, and to apply the same standards for both petrol and diesel-fuelled vehicles in the near future. All of these measures were scheduled for implementation by 1999. Based on this proposal the MOT revised the emission regulations in May 1991 to incorporate the short-term limits. The major changes were as follows:

- Reductions in NO_x emissions from commercial vehicles.
- Introduction of particulate standards and more stringent smoke limits for diesel vehicles. Smoke limits were reduced by 20% in 1993 for light and medium duty diesel vehicles. Heavy duty and passenger vehicle limits were to follow suit in 1994.
- Revision of test cycles and measurement modes.

In 1991, the EA set up a committee to consider the introduction of limits for motorcycles and special vehicles (e.g. off road).

A joint study conducted by MOT/MITI/EA proposed legislation to further reduce NO_x emissions in urban areas. These proposals were adopted in December 1992, to take effect in December 1993. The objective was to control both, the population of older vehicles and impose even tougher emission limits for new vehicles. It is proposed that the regulations will apply to all diesel vehicles in the specified areas. However, there are a number of derogations for various classes of older vehicles. In 1992, the Law Concerning Special Measures for Total Emission Reduction of Nitrogen Oxides from Automobiles (Automobile NO_x Law) was passed. With regard to specific areas in which such pollution is most severe, the law sets forth the fundamental policies and plans for reducing the total volume of automobile emitted nitrogen oxide, establishes nitrogen oxides emission standards for specific automobiles which are registered in those areas, and employs necessary measures for restricting the nitrogen oxides emissions resulting from use of automobiles for business activities,

In 1996, the MOT announced its plans to implement more of the proposals of the CCEPC suggested in December 1989. A report, the 'Future Policy for Motor Vehicle Exhaust Emission Reduction' was submitted in 1996. Based on this Report, the following measures listed below were scheduled for enforcement in 1998 or 1999.

- (1) Emission reduction of hydrocarbons, etc. through introduction of an exhaust emission control standard for two-wheeled motor vehicles,
- (2) Emission reduction of hydrocarbons, etc. through strengthened exhaust emission control standards for petrol/LPG motor vehicles, and
- (3) Employment of low-benzene petrol by means of automotive fuel quality regulations.

In June 2001, Japan's legislature, the Diet, enacted a law designed to further tighten controls on NO₂ and PM emissions from diesel powered vehicles in order to improve air quality in major urban areas. The law applies to a total of 196 city, ward, and town and village governments in Tokyo, Saitama, Chiba, Kanagawa, Hyogo, and Osaka (<http://environment.about.com/library/weekly/blairpol1.htm> as on September 5, 2002).

In April 2002, the Central Environment Council finalized its fifth report of deliberations on 'Future Policy for Motor Vehicle Exhaust Emission Reduction'. The report's recommendations include (1) new long-term targets for emissions from diesel motor vehicles, which will be effective from 2005, (2) new long-term targets for emissions from petrol motor vehicles and deadlines for achieving

them, (3) a revision of test modes, (4) a reduction of sulphur in petrol, and other items. The Ministry of the Environment plans to strengthen regulations based on this report.

Diesel vehicles

The new regulation calls for reducing PM emissions from trucks and buses by up to 85 percent and NOx emissions by 50 percent from the levels set in the short-term diesel auto emission regulation that is scheduled for enforcement between fiscal 2002 (starting April 1) and fiscal 2004 (ending March 2005). The MOE is also preparing to enforce a tougher regulation on hydrocarbons, NOx, and SOx emitted from petrol-powered vehicles, so-called the Ultra-Low Emission Vehicles (ULEVs). The new regulation toughens the short-term emission limit that will be in effect between 1 April 2002, and 31 March 2005 (fiscal 2002-2004). For example, the new PM emissions level would be 0.027 gram per kilowatt per hour (kW-h) compared to 0.18 gram per kW-h under the 2002-2004 regulation, or an 85 percent reduction. The standards for NOx emissions for the same category of trucks would be 2 grams per kWh compared to 3.38 grams under the 2002-2004 regulation.

Petrol vehicles

For petrol-powered passenger vehicles weighing more than 1.25 tonnes, the new standards for PM must be less than 0.014 gram per kilowatt-hour compared with 0.056 gram per kWh under the 2002-2004 regulation, and NOx must be less than 0.15 gram per kWh from 0.3 gram/kWh under the 2002-2004 regulation.

The Japanese New Long-Term Regulations will start from October 2005. The details of the vehicle exhaust emission standards in Japan are given in Annex 4.3.

India

The Motor Vehicle Act of 1939 was amended in 1988 to regulate vehicular emission in India. The Motor Vehicles Act and the Central Motor Vehicles rules (CMVR) are the principal instruments for regulation of motor vehicular traffic throughout the country. The implementation of various provisions of this Act rests with the state governments. The Ministry of Road Transport and Highways (MoRT&H) acts as a nodal agency for the formulation and implementation of various provisions of the Motor Vehicle Act and CMVR. The Ministry of Road Transport & Highways is advised by the CMVR-Technical

Standing Committee on various technical aspects related to CMVR. This Committee has representatives from organisations such as the Ministry of Heavy Industries (MoHI), Ministry of Road Transport and Highways (MoRT&H), Bureau of Indian Standards (BIS), testing agencies such as the Automotive Research Association of India (ARAI), Vehicle Research and Development Establishment (VRDE), Central Institute of Road Transport (CIRT) and industry representatives from the Society of Indian Automobile Manufacturers (SIAM) and Automotive Component Manufacturers Association (ACMA).

Although the Air Act, 1981, and the Environment (Protection) Act, 1986 provide for the prescription of automobile emission standards by the CPCB or Ministry of Environment and Forests, implementation and enforcement of these standards is the responsibility of the Union Ministry of Road Transport and Highways or the Transport Commissioner at the state level. For issues related to the implementation of emission regulations the MoRT&H is advised by a separate committee the Standing Committee on Implementation of Emission Legislation. The MoRT&H has formed this committee to discuss future emission norms, related test procedures and the implementation strategy, in consultation with all stakeholders.

The Supreme Court's directives

The initial active steps towards controlling vehicular pollution were taken by the Supreme Court of India in response to a writ petition filed in 1985. Judicial activism is responsible to a large extent for the substantial progress that has been made in several issues relating to reducing vehicular pollution. Greater emphasis has been laid on setting standards and promoting specific technologies by mandating their usage.

The general consensus in India was to follow European emission norms. The formal specification of emission standards for vehicles began only in 1991. In 1991, the first stage of emission norms came into force for petrol vehicles and, in 1992, for diesel vehicles. In 1996, there was a further tightening of auto emission norms and fuel quality specifications. Thereafter, the MoRT&H in consultation with the Ministry of Environment and Forests has made the emission standards progressively stricter for different categories of vehicles, thereby narrowing the gap between the standards applicable in the developed world and in India. From April 1995, mandatory fitment of catalytic converters in new petrol passenger cars sold in Delhi, Kolkata, Mumbai, and Chennai along with supply of unleaded petrol (ULP) was effected and later extended to 45 cities in the country. From 2000 onwards, ULP was made available across India. Bharat Stage I norms

(equivalent to Euro-I norms) were brought into force with effect from 1.04.2000 throughout the country for all categories of vehicles. Bharat Stage II norms, which are akin to Euro-II norms have been introduced in the National Capital Region (NCR) for passenger vehicles upto GVW 3.5T from 1 April 2000 and for heavier vehicles from 24 October 2001 in the National Capital Territory (NCT) of Delhi. In Mumbai, these have been extended from 1 January 2001 and 31 October 2001 respectively. For both Chennai and Kolkata, the corresponding dates are 1 July 2001 and 31 October 2001, respectively. Fitness norms for commercial vehicles have been tightened with effect from 28 March 2001 (<http://www.morth.nic.in/emission.htm> as on August 27, 02). Bharat Stage II norms for heavy vehicles in the four major metros have already been introduced. The emission norms for CNG and LPG vehicles were notified in the year 2000 and 2001, respectively. The Central Motor Vehicles Rules have been frequently amended to take into account the changing requirements.

The emission norms in India are behind European ones by four to five years for all categories of vehicles except for two- and three-wheelers. For them, Bharat 2000 norms are far stricter than the Euro II norms and are one of the most stringent in the world. The details of the emission norms are given in Annex 4.4.

Fuel technology

The vehicle technology and fuel system should be treated as an integrated whole. However, this has not been the case in India. The initiative for improving fuel quality was taken by the Supreme Court beginning with the phasing out of lead in petrol in Delhi, Mumbai, Chennai and Kolkata in 1994. The Ministry of Environment and Forests notified fuel specifications in 1996.

Since April 2000, unleaded petrol with a sulphur content of 0.1% has been available in the entire country. In the metropolitan cities the sulphur content in petrol has been further reduced to 0.05%. A similar programme to reduce the sulphur content in diesel was effected in 1996. At present the sulphur content in diesel available across the country has been reduced to 0.25%. In the four metropolitan cities, the sulphur content has been further reduced to 0.05%. The details of these programmes are given in tables 4.1 and 4.2.

Table 4.1 Phase-out programmes for lead in petrol

Phase I	June 1994	Low leaded (0.15 g/litre)	Cities of Delhi, Mumbai, Calcutta and Chennai
Phase II	April 1995	Unleaded (0.013 g/ litre) (+ low leaded)	Cities of Delhi, Mumbai, Calcutta and Chennai
Phase III	January 1997	Low leaded (0.15 g/ litre)	Entire country
Phase IV	September 98	Ban on Leaded fuel (only unleaded fuel)	NCT Delhi
Phase V	September 98	Unleaded (0.013 g/ litre) (+ low leaded)	All other capitals of State/Union territories and other major cities.
Phase VI	January 99	Unleaded only (0.013 g/ litre)	NCR
Phase VII	April 2000	Unleaded only (0.013 g/ litre)	Entire country

Source: TEDDY 2001

Table 4.2 Phase-out programme for sulphur in diesel

Phase I	April 96	Low sulphur (0.5%)	Four metros and Taj Trapezium
Phase II	August 97	Low sulphur (0.25%)	Delhi and Taj Trapezium
Phase III	April 98	Low sulphur (0.25%)	Metro cities
Phase IV	April 99	Low sulphur (0.25%)	Entire country
Phase V	April 2000	Low sulphur (0.05%)	NCR, Mumbai, Chennai and Kolkatta (in 2001)

Source: TEDDY 2001

The maximum limits for critical ingredients such as Benzene in petrol have been specified only recently and a limit of 5% m/m and 3% m/m has been set for petrol in the country and metros respectively. The benzene content in petrol has been further reduced to 1% in Delhi and Mumbai.

In addition to petrol and diesel, CNG and LPG are permitted as auto fuels. In a number of cities, Delhi, Mumbai, Surat etc. CNG is quite popular. In fact in Delhi, as per the directives of the Supreme Court, the entire bus fleet and intermediate public transport (autorickshaws and taxis) is being steadily converted to CNG. Auto LPG is being promoted in the major cities of the country by a number of oil companies. Alternative fuels such as di-methyl ether, bio-

diesel, hydrogen, electric and fuel cell vehicles etc., are at various stages of experimentation.

Phasing out of vehicles

There is no age limit specified for vehicles at the national level. However, in Delhi and Mumbai, there are age limits. In Delhi, as per the specification of the Supreme Court, commercial vehicles more than 15 years old were phased out with effect from December 1998. Buses that are 8 years old or more have also been phased out. The replacement of pre-1990 and conversion of post-1990 autorickshaws and taxis to clean fuels is in progress in the capital. In Mumbai, three-cylinder diesel engine taxis are being phased out. However, no age limit has been imposed on private vehicles.

Inspection and maintenance of in-use vehicles

In India as currently prescribed by the Central Motor Vehicles Rules, only transport vehicles, that is, vehicles used for hire must undergo periodic fitness certification. The large population of personalized vehicles is not yet covered by any such mandatory requirement. The Supreme Court in its 1997/98 order required immediate setting up of automated inspection and maintenance facilities for commercial vehicles in the first phase and comprehensive I&M programmes to be started by the Transport Department and private sector.

Recommendation of various committees

White paper by MoEF

In view of the rapidly growing environmental pollution in the national capital, the MoEF came out with a white paper on pollution in Delhi with an Action Plan (<http://envfor.nic.in/divisions/cpoll/delpolln.html> as on 5 September 2002).

The white paper covered various aspects of pollution control, including vehicular and industrial pollution, solid waste management and noise pollution. The proposals and the action plan were concurred on 8 August 1997. The measures for controlling vehicular pollution included improved traffic management, strengthening of public transportation to reduce congestion and the use of personal vehicles, improvement in the quality of fuel, decongestion of Delhi through the relocation of wholesale markets, and better land use planning. In the paper, emissions from each category of vehicles were routinely identified. However, there was no focussed approach or cohesive strategy for their implementation.

Other directives of the Supreme Court

Some other important directives of the Supreme Court as on 2 September 2002 are listed below (<http://www.iglonline.net/legal.asp> and <http://www.teriin.org/urban/court.htm>):

- 1 The Court directed that the entire city bus fleet of the capital be steadily converted to a single fuel CNG, by March 2001. The date was extended to 31 January, 2002. On 5 April 2002, the Supreme Court imposed Rs 500 fine effective from 1 February 2002 and Rs 1000 effective from 6 April 2002, on diesel buses, which continued to ply on the roads against the Court's orders. The apex court also directed that priority should be given for supply of CNG to transport sector all over the country. The Court also gave orders to augment public transport (stage carriage) to 10,000 buses by March 2001.
- 2 Measures to check fuel adulteration: the Court directed that two independent fuel testing laboratories be established. One such independent laboratory has been commissioned at NOIDA.

EPCA Committee Report

The Supreme Court vide its order in March 2001 directed that a report be submitted on clean fuels indicating which fuels can be regarded as clean, non-polluting and not injurious to health. The Environment Pollution (Prevention and Control) Authority (EPCA) for the National Capital Region in its report to the Supreme Court on clean fuels reported that only non-hydrocarbon fuels such as electricity, solar energy and fuel cells do not emit noxious pollutants (EPCA, 2001). However, these fuels are not yet commercially available for automobiles. The hydrocarbon fuels which are available and which can be regarded as 'environmentally acceptable fuels' include CNG, LPG and propane. It further stated that ultra low sulphur diesel (ULSD with a maximum sulphur content of 10-30 ppm) and petrol (without lead and reduced benzene level) could be considered environmentally acceptable provided that they were unadulterated and used in combination with after-treatment devices such as particulate traps and catalytic converters. Diesel with a sulphur content of 500 ppm, which is compatible with Bharat Stage II emission norms cannot be regarded as environmentally acceptable and must be treated as a transition fuel permitted for a limited period. Similarly, with petrol, though phasing out of lead and reduction of benzene has considerably improved the quality of fuel, it cannot yet be called an environmentally acceptable fuel. It would be necessary to use catalytic converters for treatment of exhaust gases, stop adulteration and further reduce polluting constituents such as sulphur, aromatics, and olefins. The report

suggested that the Government should promote all environmentally acceptable fuels. Also, the Government should make plans for improving the quality of other fuels with relevant exhaust treatment devices and engine technology so that different options can compete in the market.

V M Lal Committee Report for Mumbai

In Mumbai, a writ petition was filed in 1999 in public interest by the Smoke Affected Residents Forum seeking appropriate directions from the High Court with a view to controlling and reducing vehicular emissions in the city. Some leading doctors and cardiologists of Mumbai had averred that up to 40% of the inhabitants suffer from respiratory diseases and illnesses such as asthma, bronchitis, etc. According to some studies, the children in Mumbai have a markedly stunted development of lungs when compared to children in Chennai. The Mumbai High Court also constituted a committee under V M Lal, then Transport Commissioner under an order dated 15 December 1999 (http://www.mahatransport.org/vm_lal/chapters.htm as on 26 August 2002). The Committee recommended improvement in fuel quality, use of alternative fuels such as CNG/reformulated petrol, desirability and feasibility of converting the existing buses/taxis to CNG, assessment of the existing emission norms, applicability of EURO I and II norms to commercial vehicles, phasing out vehicles, improvement of emission levels of in-use vehicles and prevention of fuel adulteration, etc. These recommendations have been placed before the High Court and are under various stages of consideration/implementation.

Mashelkar Committee Report

On 13 September 2001, the Government of India constituted a committee of experts of national repute, headed by Dr R A Mashelkar, Director General, Council of Scientific and Industrial Research to recommend an Auto Fuel Policy for the major cities of the country, to devise a road map for its implementation and recommend suitable auto fuels, automobile technologies and fiscal and institutional measures. The Expert Committee submitted its final report on 25 September 2002 (MoPNG 2002). The report suggests that the policy for the country must aim at -

- 1 Achieving the twin objectives of providing an assured supply of fuels at minimum cost and meeting environmental concerns by making available:
 - liquid fuels (petrol and diesel) of the specified quality as the main auto fuels throughout the country ;

- alternative auto fuels (CNG, LPG, etc.), along with liquid auto fuels, in the cities having high vehicular pollution to enable the vehicle owners to meet the prescribed emission norms in such cities by choosing appropriate combination of fuel and engine technology;
- 2 Protecting consumers against supply disruptions and price risks.

The report proposes two separate road maps, one for new vehicles and one for in-use ones, excluding cars and 2-wheelers. But it marks out 11 cities, Delhi, Kolkata, Mumbai, Chennai, Hyderabad, Ahmedabad, Surat, Pune, Bangalore, Kanpur, and Agra for stricter standards due to the high levels of pollution in these cities. New vehicles (other than 2- and 3-wheelers) in these cities would have to meet Euro III norms by 1 April 2005 and Euro IV emission norms by 1 April 2010. However, the rest of the country will have Euro III standards by 1 April 2010. For two- and three-wheelers, the Committee recommends Bharat Stage II norms by 1 April 2005 and Bharat Stage III norms preferably from 1 April 2008 but not later than 1 April 2010 in the entire country. Whereas, in the case of in-use vehicles such as city buses, taxis and three-wheelers, from 1 April 2004 and 1 April 2008, only vehicles which meet the emission norms of 1996 and Bharat Stage I, respectively, will be allowed to run. This is only applicable for vehicles registered before the introduction of Bharat Stage II norms. In other words, vehicles over 8 years will not be allowed to run. All other vehicles will have to conform to the emission norms as on the date of registration.

The report recognized that for the purposes of achieving best air quality it is not necessary for the government to mandate the use of any specific fuel or engine technology. Government should only set the emission standards. This would allow flexibility in absorbing the latest technology and location-specific solutions as and when they develop.

Conclusions

The harmful effects of the growth in vehicle emissions of regulated pollutants – hydrocarbons, oxides of nitrogen, carbon monoxide, and particulates – on human health and ecosystems are well documented, and scientific evidence continues to grow. In past few years major initiatives have been taken by both industrialized and developing countries to control vehicular emissions. The most important initiative has been adoption of progressively stringent emission standards for new vehicles. Strong emission control programmes in several countries have produced impressive emissions reductions and fuel efficiency improvements over the last three decades. Given the current trend, any new

vehicle on road by the end of this decade would have to meet a very low emission level, irrespective of what fuel is being used. Some important initiatives taken by different countries to reduce vehicular emissions are listed below.

- The European Union has put stringent limits on the sulphur content of both diesel and petrol (50 parts per million (ppm) maximum by 2005 and recently proposed a further shift to near-zero (10 ppm maximum) to zero-sulphur levels for both fuels by 2009.
- The US Environmental Protection Agency (USEPA) recently adopted a rule that will reduce the emissions of new diesel trucks and buses by 90 to 95 per cent from current levels by the end of this decade. Near-zero sulphur (10 ppm or less) would be introduced by 2007, in all fuels.
- The European Union has made a voluntary agreement with the European Car Manufacturer's Association to reduce per-vehicle greenhouse gas emissions by 25 percent from a 1995 baseline, by 2008.
- In Japan, the national government has established a series of weight-class emission and fuel economy standards. Their aim is to set up the most stringent but technologically feasible standards, and to apply the same standards for both petrol and diesel-fuelled vehicles in the near future.
- Several developing countries, including China, India, Mexico, South Korea, Thailand, appear to be on the track to reach world-class vehicle emission standards within the next decade. Benzene levels in petrol should be capped at no more than one percent worldwide. In addition, the aromatics content should be controlled.
- Currently, vehicle emission norms in India are behind Europe by four to five years for all categories of vehicles, excluding two- and three-wheelers. Hence, both the domestic and foreign markets are likely to move towards more stringent emission regulations.
- A number of countries have introduced alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG), gasohol (ethanol blended with petrol), bio-diesel etc. for use in motor vehicles. When they are introduced standards for environmental performance must be specified.

Issues for consideration

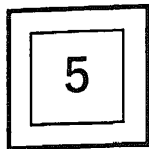
Policymakers in India will need to show leadership to ensure that future generations can enjoy personal mobility without paying a high price in terms of disease and environmental degradation. The following issues are expected to provide valuable guidance in formulating a cohesive set of policy signals to industries that produce vehicles and their fuels.

- Vehicles are manufactured globally by a limited number of companies, which operate not only in the developed countries but also in developing countries. These companies produce vehicles that conform to varying degrees of stringency of emission norms depending upon the respective jurisdiction. Hence, lack of availability of advanced technology is not likely to pose any problems in the introduction of more stringent emission norms in India.
- Vehicle technologies and fuel properties are very closely intertwined. This has become increasingly clear as emission regulations have become more stringent. Fuel parameters such as lead or sulphur content would be (and have been in the past) controlled as a precondition to introducing advanced vehicle technologies. Hence vehicles and fuels would have to be treated as a system.
- The liquid fuels (petrol and diesel) will comprise the significant share since improving the liquid fuel quality is the most cost-effective approach (as compared to introducing alternative fuels) if one takes into account the available refining and inland infrastructure right from refineries to retail outlets that already exist in the country.
- It would logically appear more cost effective to upgrade from Euro II to Euro IV directly at least in refineries with catalytic reformers, catalytic crackers and/or a hydrocracker instead of following a two-step approach of upgrading from Euro II to Euro III, and then to Euro IV as considerable savings in cost and time can be achieved.
- Economic instruments should be used to promote clean fuels. Since the upgradation of refineries is time-consuming and capital-intensive, incentives can be graded across time if investments are made earlier. Further, the government could consider limiting the incentives for that

period so that the refineries are compelled to take immediate steps to upgrade the refineries and avail of the incentives to be able to recover their investments.

- In certain identified cities (as discussed earlier), the earlier phase-in of Euro IV fuel quality would yield significant benefits even without matching Euro IV vehicle technology. The Euro IV vehicle technology can be brought in as and when vehicle manufacturers are ready. Earlier indications from the Society for Indian Automobile Manufacturers (SIAM) were that by 2007/08 Euro IV vehicles (other than 2-and 3-wheelers) could be introduced in the country. While it is recognized that maximum emission benefits of Euro IV fuel would accrue only with Euro IV vehicle technology, use of Euro IV fuel with current vehicle technology will also yield emission reduction benefits.
- Vehicles operating on different fuels frequently compete for the same market. In the past, governments have often set different standards for different fuels, thereby introducing distortions into the marketplace and undercutting the goals of clean air. For instance, if both petrol and diesel cars compete for the same market and the latter has a more lenient NO_x standard, then this would give it a competitive advantage stimulating its sales. Hence future emission standards for vehicles are expected to be fuel neutral. The emission limits for light duty vehicles in the US under the Tier 2 program are going to be fuel neutral.
- Emissions test procedures should reflect real-world operating conditions for all vehicles and engines.
- Manufacturers should be responsible for in-use (real world) emissions in normal use.
- Inspection and maintenance programme should be used to control lifetime in-use vehicle emissions. Given the fact that the today's vehicles rely on proper functioning of emission control devices to keep pollution levels low, a minor malfunction in this system can boost emissions significantly. Hence well managed I & M programmes are key to controlling in-use emissions. The existing PUC system in India is not effective and adequate. I & M programmes should be made mandatory and more effective requiring active participation of the vehicle manufacturers.

- Manufacturers should start thinking about equipments such as Onboard Diagnostics (OBD) that identify failure modes and store failure data should be required for all new vehicles. These computers are capable of identifying problems that result in high emissions.



Fuel quality and alternative fuels

Introduction

Fuel quality is a predominant factor affecting vehicular emissions and ambient air quality. The quality of conventional fuels (mainly diesel and petrol or petrol) has been changed to ensure reduced emissions. To reduce emissions both, at the local and global level, alternative fuels such as gaseous and bio-fuels have emerged. This discussion on fuels broadly covers future developments and they have been broadly classified into three categories, listed below:

Conventional fuels

- Diesel
- Petrol

Gaseous fuels

- Compressed natural gas (CNG)
- Liquefied petroleum gas (LPG)

Bio-fuels

- Ethanol
- Bio-diesel

This chapter provides an overview of the current and future fuel quality standards of conventional auto fuels in Europe, US, and India. International experience on the use of cleaner fuels in the transport sector and the current status in India has also been discussed. The policy recommended for auto fuels by the Mashelkar Committee and its implications in the light of the EPCA report has also been analyzed.

Conventional fuels

While NO_x and PM are the main pollutants from diesel engines, emissions from gasoline engines comprise mainly of HC and CO. The Euro IV level of regulations for these pollutants is of interest today in the country. International experience has shown that liquid fuels (petrol or diesel) conforming to Euro IV fuel quality standards in Euro II compliant vehicles fitted with appropriate post combustion emission control devices can give environmentally acceptable

emission results. For example, using a diesel particulate filter in a Euro II compliant diesel engine bus with Euro IV fuels will yield significant reductions in PM. These will be comparable to PM emissions from heavy duty CNG applications with three-way catalysts as has been demonstrated in trials on diesel engines used in different applications in London, New York and Hong Kong.

More advanced emissions regulations such as the Euro V regulations have still not been mandated with any deadline in Europe. In Europe, the Euro IV regulations scheduled to come into force by 2005 are less stringent than the US emission regulations of 2007. Also since Euro III standard fuels do not allow the use of the latest emission control devices, Euro IV fuel standards are very crucial to ensure that these devices can be used effectively. Since further developments in regulations will target a fuel neutral approach, targeting such levels requires significant development in vehicle technologies and also fuel quality. Hence, fuel quality and emissions technologies till the Euro IV level only are discussed.

Diesel

Several attempts have been made over the years to reduce harmful components in diesel and to improve its combustion properties and performance. Some of the ways to improve the fuel efficiency and reduce tailpipe emissions of a diesel vehicle are:

- 1 Improve engine performance by increasing cetane number
- 2 Bring down vehicle emissions by
 - reducing poly aromatic hydrocarbon (PAH) content
 - reducing sulphur content
 - reducing T95
 - reducing density
- 3 Maintain a certain level of lubricity

Annex 5.1 gives a short description of each of these fuel properties.

European Union

The improvements to diesel quality made in Europe have been adopted in most Asian countries including India. They are listed in Table 5.1. Recently, the European Union set 1 January 2009 as the deadline for an EU-wide changeover to zero sulphur diesel in road transport, and the Council of Ministers approved the measure on 7 February 2003.

Table 5.1 Fuel quality specifications – past, present and future

Property	Euro II	Euro III	Euro IV
Density, g/cc	0.82-0.86	0.82-0.845	0.82-0.845
Cetane number	48	51	51
PAH content, wt %	-	11	4
Sulphur, ppm (max)	500	350	50
T 95, deg C (max)	370	360	360
Lubricity, Wear Scar Diameter, mm (max)	460	460	460
Year of Implementation in Europe	1998	2000	2005
Year of Implementation in India	2000	2005*	2010*

*Proposed by the Mashelkar Committee in selected cities.

United States

The diesel quality applicable in major regions in the US is based on the American Society for Testing and Materials ASTM D 975 and given in Table 5.2. Because of the cold climate in the US (similar to many European countries) there is focus on the cold flow properties, which are not so significant in the Indian context. Properties such as cold filter plugging point (CFPP) and cloud point are very important properties for diesel in US when compared to the diesel produced in other countries.

(www.chevron.com/prodserv/fuels/bulletin/diesel/l2_5_1rf.html, 10 August 2002).

Table 5.2 ASTM D 975 diesel specifications

Property	Low S 1-D	Low S 2-D
Flash point, Deg C	38	52
T90, Deg C	288	338
Sulfur, % wt	0.05	0.05
Cetane number, min	40	40
Aromaticity, %vol	35	35

Table 5.2 lists the minimum requirements for guaranteeing an acceptable performance for the majority of users. There are additional constraints which meet specifications for products, pumped in cross-country pipelines.

Diesel specifications are less stringent in the US than in Europe and Japan both of which have a higher minimum cetane number. Since PAH and a higher T95 contribute significantly to particulate emissions, the major criteria pollutant, they have been significantly reduced. California has a more stringent

specification for diesel fuel based on the California Air Resources Boards recommendations.

International experience with cleaner diesel

Across the world, a number of countries are moving towards reducing emissions from diesel vehicles — a significant source of both, NO_x and PM, in many countries. Environmental agencies have continued to dramatically tighten exhaust emission standards. In an effort to enable manufacturers to achieve low pollution levels, improvements in the quality of diesel especially in its sulphur content are being mandated. Internationally, financial incentives such as tax differential, credits have encouraged refineries to start producing ULSD with a maximum sulphur content of 50 ppm (see Annex 5.2 for details).

Petrol

Quality improvements in petrol have also focused on two aspects, first, on combustion improvement and, second on the reduction of emissions from combustion. Some of the ways to improve the fuel efficiency and reduce tailpipe emissions of a petrol vehicle are:

- 1 Improve engine performance and combustion by increasing octane number
- 2 Bring down emissions by reducing
 - Aromatics content
 - Olefins content
 - Sulphur
- 3 Reduce evaporative emissions by addressing
 - Reid Vapour Pressure (RVP)
 - Vapour Lock Index (VLI)

Annex 5.3 gives a short description of each of these fuel properties.

European Union

The improvements to petrol quality made in Europe have been adopted in most Asian countries including in India. These are listed in Table 5.3.

Table 5.3 Petrol specifications – past, present and future

Property	EURO II	EURO III**	EURO IV
Research Octane Number (RON)	90	95	95
Motor Octane Number (MON)	82	85	85
Olefins, vol %	NA	18	18
Aromatics content, vol %	NA	42	35
Sulphur, ppm	500	150	50
Benzene, vol %	1	1	1
Year of Implementation	1998	2000	2005
Year of Implementation in Europe	2000	2005*	2010*

NA- not applicable, no limit for olefins and aromatics content in EURO II.

*Proposed by the Mashelkar Committee in selected cities.

United States

The improvements to petrol quality in the US have followed a different approach from the European one. In US the levels of local air pollutants in different states have directed the changes in petrol quality with different states having different norms for petrol. California has more stringent specifications for petrol than that of the reformulated petrol, which is followed in many states in US with zero olefins and very low level of aromatics in petrol.

The minimum oxygen content in petrol of 2-wt % that was mandated after the introduction of the Clean Air Act of 1992 led to a significant increase in the percentage of MTBE blended with petrol. With a growing perception of the use of MTBE leading to groundwater pollution and its impact as a carcinogen increasing, refiners in US had to look for other alternatives in order to meet the minimum oxygen content requirement. Many refiners in California were of the view that they could meet the emissions reduction requirements even without the oxygenates. Of the substitutes for MTBE available such as like TAME, ETBE, TBA, and ethanol, ethanol has emerged as the major oxygenate.

India

The Fuels Sub-Committee of the Bureau of Indian Standards (BIS) has laid down the specifications for fuel quality periodically based on emission norms, which are changed and notified in the Motor Vehicles Act. The Supreme Court of India constituted a committee in 1986, under the EPCA (Environment Pollution (Prevention and Control)) Act for the National Capital Region, which has initiated a number of changes in fuel quality. In September 1991, the Ministry of Petroleum and Natural Gas constituted an Expert Committee on Auto Fuel

policy under the chairmanship of Dr R A Mashelkar, Director General, CSIR. A year later, on 13 September 2002, the Committee submitted its final report to the cabinet and recommended a road map for its implementation (MoPNG 2002). If the recommended changes are accepted by the government, they would have to translate into changes in the BIS specifications (for fuel quality) and the Motor Vehicles Act (for emission standards). The report recognized that for achieving the best air quality it was not necessary for the government to mandate the use of any specific fuel or engine technology, but the Government should only set the emission standards. This would also allow flexibility in absorbing the latest technologies and solutions suiting specific locations.

Review of policies in India

Numerous government committees have looked into different aspects of fuel quality and the roadmap for such an improvement. Important studies and their recommendations are summarized below:

- 1 The Hydrocarbon Vision 2025 – This report was prepared by a committee constituted by the Prime Minister to identify the future direction of the upstream and downstream oil and gas industry by considering investments and the roadmap for total deregulation of the sector (Hydrocarbon Vision - 2025 1999). This report did not directly address the issue of fuel quality standards etc, but touched upon the issues of reduction in the cross-subsidization of petroleum products. It proposed a roadmap for reducing subsidies on kerosene and LPG thereby reducing the high taxation levels on petrol and diesel. This would partly address the problem of fuel adulteration. However, adulteration is likely to continue as long as the taxes on petrol and diesel are significantly higher than those on kerosene.
- 2 The CPCB Report on Transport Fuel Quality – A committee was constituted by the Central Pollution Control Board whose objective was to propose a roadmap for up-grading fuel quality in the country. This committee recommended introduction of Euro III norms all over the country by 2005 in a phased manner (CPCB 1999).
- 3 The EPCA Committee – The main recommendation of the EPCA Committee to the Supreme Court was to mandate the use of CNG for public transport vehicles in Delhi (EPCA 2001). It also identified unadulterable diesel with a sulphur content of less than 10-ppm when used in combination with an appropriate emission control device as the only clean fuel in addition to CNG and LPG and electricity from the aspect of local pollutants. The Committee observed that considerable time would be needed to produce

diesel with a sulphur content lower than 10-ppm. It recommended mandating CNG as the fuel for all new public transport buses and conversion of all diesel buses to CNG by retrofitment. Fuels with long chain hydrocarbons (conventional liquid fuels) have higher emissions levels when compared to fuels composed of short chain hydrocarbons (CNG and LPG). This is why the Supreme Court was recommended to mandate the use of CNG as the fuel for public transport. The Supreme Court has also mandated the introduction of Euro II petrol, which contains less than 1% benzene by volume and less than 500 ppm of sulphur.

- 4 The Mashelkar Committee on an Auto Fuel Policy – The road map proposed by the Mashelkar Committee is given in Chapter 4. The Committee has presented a balanced view in terms of the effect on refineries and costs to consumers and the final report recommended movement to Euro IV standards by 2010 in selected Indian cities. These initial recommendations drew flak from many quarters including the Supreme Court for the following reasons:
- Not considering the health costs involved in deterioration of air quality in metros due to increasing vehicular pollution.
 - Not recommending Euro IV norms for metros, with a note that Euro IV norms were not yet legislated in Europe itself; however it is important to note in this context that Euro IV regulations would come into force from year 2005.
 - Not recommending quick changes in emission norms and fuel quality.
 - Not providing incentives to refineries which can upgrade their facilities before the mandated deadlines. This means that there is no possibility of refineries upgrading facilities before mandating deadlines unless there are new entrants in the oil-marketing sector and the competition induced in marketing drives refineries to change to safeguard market share thereby survival.

The final report of the Committee has also indicated the incremental cost of upgrading fuel quality to Euro III diesel quality (see Annex 5.4 for details on costs of up gradation of refineries).

Additives in diesel and petrol

Besides changes to fuel quality, oil-marketing companies add performance improving additive packages to both diesel and petrol. These additives are

becoming important with the branding of diesel and petrol. These packages would comprise:

- 1 Additives common to petrol and diesel
 - Detergents to clean the intake valve of deposits
 - Antioxidants to ensure longer life
- 2 Additives for petrol
 - Corrosion inhibitors etc.
 - Octane improvers such as MMT or ferrocene
- 3 Additives for diesel
 - Combustion improvers such as platinum
 - Cetane improvers

These would help in reducing engine maintenance and improve fuel efficiency but the packages used by different companies could be different.

Branding of fuels by oil companies will be a significant phenomenon, which will be driven by competition in the marketing sector. Branded petrol such as BPCL's Speed, IOC's Premium etc have already been launched. These branded fuels contain significant proportions of a detergent to help remove the deposits in the combustion chambers and injectors. By keeping the injectors and the combustion chambers clean, fuel injection and combustion become more efficient, thereby ensuring better fuel efficiency and also less engine maintenance. Multifunctional additives (MFA) whose main constituent is a detergent has already been mandated for three years and the petrol is supposed to be blended with these additives. This mandate is not enforced satisfactorily.

Automobile companies need to take a proactive role in identifying the major changes between these branded fuels and normal fuels and understand the impact on the engines and other related equipment.

Gaseous fuels

The two gaseous fuels, LPG and CNG, are increasingly in focus as they are considered environmentally acceptable fuels and help in reducing particulate emissions significantly when compared to the present quality of diesel. While the use of CNG for heavy-duty applications is better established than LPG, a country's supply/demand constraints determine the choice between these fuels. The Mashelkar Committee recognized that for CNG, only cities fed by natural gas pipelines and with the infrastructure for distribution can offer the choice of CNG as an alternative fuel. The limited availability of LPG for domestic use

implies a dependence on imports, which means higher costs for import terminals and inland infrastructure.

LPG

LPG is a product obtained during the petroleum refining process and during natural gas processing. LPG is a useful combination of combustion and storage properties among the gaseous fuels. It is a gas at normal temperatures and thus has the advantage of mixing with air in any proportion, therefore not posing any cold start problem. The lean combustion limit of LPG-air mixtures is also considerably higher than petrol allowing use of lean-burn calibrations, which increase efficiency and also reduce emissions.

Factors influencing growth of auto LPG

LPG, mainly propane and butane have grown tremendously in the US and many European countries for many reasons. Some of them are listed below:

- 1 In the US, LPG, especially butane which used to be blended with petrol had to be removed petrol due to a reduction in the Reid Vapour Pressure limit of petrol so that evaporative emissions could be reduced. That led to a lot of butane without any proper market and its development as an auto fuel itself.
- 2 Unlike in India, where LPG is a major domestic fuel, LPG in major developed countries is used mainly as a petrochemical feedstock. To ensure a proper market for LPG, which is an important by-product of the refining process, LPG has been developed as an auto fuel. LPG is a major auto fuel in the Netherlands, Italy, and some cities of the US.
- 3 LPG has also developed where gaseous fuels for automobiles have been encouraged and where the infrastructure required for distribution of CNG is not available or is very costly.
- 4 The main use of LPG has been in light-duty applications rather than heavy-duty applications in most countries. Annex 5.5 provides a description of the international experience with LPG in heavy-duty vehicles.

India

An important issue that LPG vehicle manufacturers must note is the composition that will be used in automobiles (see Annex 5.6 for further details). There is an automotive LPG specification that has been laid down by Bureau of Indian Standards (BIS) but it is not very different from the domestic LPG specification (Table 5.4). Specifically there is no minimum limit on propane

content in the LPG, which is the best component among the various constituents of LPG.

Table 5.4 Auto LPG specifications

Property	Limits
RVP, KPA (max)	520
95 %Volatility (max), deg C	2
Sulphur (max) PPM	150
Mercaptans (max) PPM	20
Research Octane Number (Min)*	88
1,3 butadiene, % vol max*	0.5
C5 and above, % vol max	2

*The only parameter, which are different from the domestic LPG which is used for cooking purposes.

LPG is being projected as an alternative to CNG with the latest Supreme Court verdict of 5 April 2002, recognizing LPG as the only clean unadulterable fuel other than CNG. The growth of LPG as an auto fuel would be mainly in the short term. Refineries still do not produce conventional fuels of Euro III and Euro IV quality and LPG also has a significant price advantage over petrol. The current focus by major oil marketing companies on auto LPG can be seen as an effort to project alternatives for CNG. The increasing use of CNG would affect the profitability of oil-marketing companies and the increasing focus on LPG can be seen as an effort to check the decline.

CNG

Natural gas consists largely of methane (85%–99%). It is extracted from gas wells or in conjunction with crude oil production, but it can also be produced as a by-product of landfill operations. World reserves of the gas are more widely distributed than those of liquid fuels so that developing countries such as Argentina, Bangladesh and Pakistan may see a strategic advantage in its development. Ecological advantages of natural gas include:

- It is practically sulphur-free
- Its combustion leads to very low particulate emissions
- It contains 20%–25% less carbon per energy unit than diesel (depending on the exact methane content).

Natural gas must be stored onboard a vehicle either in a compressed gaseous state (CNG) or in a liquefied state (LNG). CNG is the more common option for

vehicles. Natural gas is lighter than air. A spill would disperse into the air as opposed to pooling on the ground or entering sewer or water systems. However, in an enclosed area, natural gas will rise to the ceiling, which could be a potential fire and ignition risk.

Natural gas generally has an excellent antiknock property, which is best suited for spark ignition engines and over the years has emerged as a viable alternative for petrol in passenger cars. Due to the excellent antiknock property, engines designed specifically for natural gas fuel can use higher compression ratios than petrol engines with a consequent improvement in efficiency and power output. The antiknock performance of natural gas is best for pure methane or methane/inert gas mixtures, and declines somewhat with increasing concentrations of non-methane hydrocarbons.

With the growing focus on particulate emissions from heavy-duty diesel engine applications and with conventional fuel application requiring significant time for implementation by refineries, CNG has emerged as viable alternative for reducing particulate emissions in the short term. There are issues on the emissions performance, availability and infrastructure-related issues, which are being debated and are very crucial for the development of CNG as an alternative fuel in the Indian context. Annex 5.7 provides a brief overview on the international experience with CNG.

India

In India, the major issue as far as CNG as an auto fuel is concerned is its availability, and also its market price without any subsidies/exemptions etc. Oil and gas marketing has been free from government controls since 1 April 2002. This will allow gas marketing companies such as GAIL to price gas at market determined levels, though the government continues to control the pricing of natural gas through GAIL. The determinant of gas price will be the relative price when compared to LNG and there is pressure on companies like GAIL to price domestic natural gas at the levels of LNG in order for LNG to be competitive for all sectors.

One factor which is to be noted with regard to the growth of CNG in heavy-duty applications, is the relative cost of the technology and fuel when compared to conventional fuels and their technologies. The current cost difference could be a major discouraging factor if CNG is not mandated (unlike in Delhi where CNG has been mandated as the fuel for city buses) and equivalent technology in terms of emissions is available from conventional fuels like diesel and petrol.

An important aspect of the emissions from natural gas is its methane and ethane content. This is not standardized in India and the composition of natural gas varies with source and the downstream processing after production. Important properties of gas quality standards that need to be considered in India are presented in Annex 5.8.

Safety issues

Safety studies on using LPG as an auto fuel, point out that LPG poses a greater safety risk than CNG (CONCAWE 1995). Unlike natural gas, LPG vapours are heavier than air and any leaks will pool at the ground level. But the flammability limits of LPG are also as broad as the limits for natural gas. There are some countries in Europe where LPG vehicles are not allowed to be parked in enclosed places due to this enhanced risk factor. There are very strict norms in place for designing LPG storage cylinders and other safety related accessories for automobiles in India also.

Bio-Fuels

Bio-fuels have been attracting worldwide attention. The consumer wants a cleaner fuel that can lower the risks to environment and health. Governments aim to reduce reliance on imported energy and promote domestic renewable energy programmes, which use domestic resources and create new economic activities. The two bio-fuels, gasohol and bio diesel, have a promising future in the country.

Gasohol – ethanol blended petrol

The country's experiences are briefly discussed in Annex 5.9 with some lessons for the Indian context. The latest policy decisions taken in the Indian context are summarized below along with the concerns that need to be addressed.

India

In India ethanol as a blend component for petrol has been in focus since 1997 when there was a private members bill placed in Parliament. In 2001, three pilot demonstration projects for the distribution of ethanol (at the 5 % level in petrol) was launched at two places in Maharashtra and one in Uttar Pradesh. India depends heavily on oil imports with the import bill as high as 17.5 billion dollars last year so the biofuels programme is being pursued to reduce oil imports. The sugar and distillery industry would gain immensely from higher by-product realizations and higher capacity utilization as the sugar industry is facing a crisis

of excess sugar production and reduced domestic demand. There are some fears of a possible increase in molasses prices, which is the main feedstock for production of ethanol.

Policy developments

The government is determined to push ahead with increasing the use of ethanol as an alternative fuel. Recent announcements have mandated blending of ethanol upto 5 % in nine states (Andhra Pradesh, Karnataka, Maharashtra, Tamilnadu, Punjab, Haryana, Uttar Pradesh, Gujarat, Goa) and four union territories (excluding Delhi) from 1 January 2003 which will later on be mandated for the entire country. The percentage of ethanol blended in the three pilot projects will be increased to 10 % to increase the mandated blend percentage to 10 % at a later date. This policy has not been co-ordinated according to the time frame for changes in fuel specifications as recommended by the Mashelkar Committee.

Economic impact

The economic aspects of such a decision have not been studied, and so the costs of such a decision are yet to be evaluated by the government. While there are many similarities in sugarcane production between Brazil and India many factors differ and should be noted. The issue of subsidies, which led to the growth of ethanol in Brazil and the growth of the oil industry in Brazil with ethanol as a major fuel, are situations very different from the Indian scenario. It is also to be noted that some refineries in India already produce oxygenates such as MTBE, TAME in significant quantities and mandating ethanol to the extent of 5 % will directly affect these refineries.

Change in refinery end petrol standards

There are some technical issues on the automobile front, which are being addressed, but another important technical aspect of the introduction of gasohol is the effect it would have on the refinery petrol blending schemes. Ethanol blends have a higher Reid Vapour Pressure (RVP) when blended in petrol, which will lead to limitations on the base refinery petrol blends. Targeting lower RVP levels for petrol in the refinery would be at an additional cost which should also be evaluated. Studies carried out by the US Environmental Protection Agency (US EPA) and CARB evaluated this cost to the refineries. Similar studies should be conducted in the Indian context to ascertain the real cost of ethanol. There have been changes made in the refinery end petrol quality in US in order to

account for the increase in the RVP after blending ethanol to the extent of 5 % – 10 %.

Quality and pricing

The issues that are of concern to the quality and price of gasohol are summarized below:

- The volatility of petrol blended with ethanol, the effect of resultant evaporative emissions and also the general engine performance need to be studied. Though there are some studies on the engine emissions being conducted by IOC (R&D), these areas have not received due attention.
- There is a need to change the RVP standard of petrol produced in the refinery end to ensure that after blending at the depot, the final product meets petrol quality standards. Also there is need to look at the summer specifications of petrol specifically from the RVP point of view.
- Corrosion of automobile parts has also been a concern with the use of gasohol and needs attention.
- There are some studies, which indicate the lowering of stability of petrol blended with ethanol. This could lead to deposit formation on inlet valves etc., which again would need to be studied.
- The petrol prices could increase with ethanol blending being made mandatory, to begin in nine states and four union territories with effect from 1 January 2003.

Bio-diesel

Bio-diesel is esterified oil either from edible oil sources or non-edible oil sources. The base oils used for production of bio-diesel are different in different countries and thereby the properties of bio-diesel will also vary with the source of oil. The major properties such as cetane number, are very similar to those of conventional diesel which enables their use with little or no modification to the current design of engines. They also have some properties, which give them a distinct advantage over conventional diesel, but when compared to conventional diesel, their regulated emissions are not significantly lower. The fact that they are zero sulphur diesel enables the use of all advanced after-treatment devices, which are extremely sensitive to sulphur in diesel thereby ensuring low emissions. The measures taken in different countries to increase the use of bio-diesel are given in Annex 5.10.

India

In India the development of bio-diesel is at a relatively nascent stage. Potential sources of bio-diesel oil seeds have been identified and also some experiments on some of the trans-esterified oil from these seeds are underway. Indian Oil Corporation is undertaking emission studies and non-edible oil seeds are being developed by the Ministry of Agriculture. There are major issues concerning the cost of bio-diesel, which have not been studied in detail but are very important for its growth as an alternative fuel. The policy as far as use of bio-diesel is also not yet clear, i.e., uses of bio-diesel as a neat fuel or in blended form along with conventional diesel. This would be very important in understanding the effect on engines. Some indications are available from the Ministry of Rural Development on the proposed roadmap of development of this fuel. The major crop identified is the *Jatropha* non-edible oil seed, which is easy to grow and has a very short growth cycle compared to some other non-edible oil seeds. The esterified oil of *karanja* oil seeds in Karnataka is being used for power generation and in diesel generator sets. Important components of the production of bio-diesel are methanol, ethanol for the trans-esterification reaction. In India, ethanol could be used for this process, as there is a surplus of it. The Mashelkar Committee has identified a few oil seeds for bio-diesel production.

Biofuels will receive increasing importance in the years to come as the focus on reducing CO₂ emissions increases many countries are promoting biofuels from this viewpoint. The growth of biofuels would have a positive impact on the agricultural income and also reduce the wastage of agricultural land.

Institutional mechanisms and enforcement

The major changes discussed in this chapter both for conventional fuels and alternative fuels require enforcement in the following areas to ensure that the identified emission benefits are achieved.

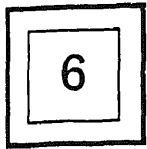
- Control over the quality of petrol and diesel with specific enforcement to prevent adulteration. This will also have to be checked by pricing which is possible in the long term (5–7 years), but in the short term, enforcement by checking from oil companies, government agencies, and voluntary organizations would be very important to achieve emission targets.
- Strict adherence to safety norms for CNG and LPG at various levels of transmission, distribution, in vehicle conversion kits, fuel storage in vehicles, etc. This will be the most important enforcement issue along with that of fuel quality with gaseous fuels.

Conclusions

Automotive fuels in developing countries are generally dirtier than those of developed countries. Clean fuels offer the most promising approach to reducing harmful pollutant emissions from motor vehicles. The following issues are expected to provide valuable guidance in formulating appropriate strategies to promote cleaner fuels in the transport sector in the country.

- The roadmap for change of diesel and petrol fuel quality will most likely be based on the recommendations of the Mashelkar Committee report. With intervention from courts the deadlines might change significantly but its philosophy will remain the same.
- Competition in the oil marketing sector will be another important driving factor for change in fuel quality.
- The absence of any concrete incentives for oil companies will mean that fuels of a certain quality will not be produced before the mandated deadlines unless competition in the oil market drives the change.
- Technical issues concerning the use of additives in fuels need extensive study by the automobile sector with the introduction of branded fuels in the country due to the deregulation in the oil-marketing sector.
- The introduction of the ethanol mandate in India from 1 January 2003 starting with nine states and four union territories is likely to influence the price of petrol if a sufficient reduction in taxation levels of petrol is not announced.
- Technical issues arising out of the ethanol blending mandate such as volatility of petrol, which would influence the evaporative emissions from petrol powered vehicles should be given attention by both automobile and oil-marketing companies.
- Automobile companies should ask for a review of standards of diesel and petrol with the introduction of ethanol and bio-diesel as blend stocks for these fuels.

- Bio-diesel is still in the development phase and should be a focus area for companies whose core competence is the diesel fuel-based technologies, and build synergies to gain an initial advantage in this sector.
- Policy initiatives on the introduction of bio-diesel as a blend component in conventional diesel are being taken and this area will see development in the next few years.
- The standards of current auto LPG quality in India could actually lead to more toxic unregulated pollutants, which need to be examined in detail.
- There is currently no standard for CNG quality in the country other than some individual informal agreements between the gas supplier and the transport operators. There should be pressure from the automobile companies to standardize the quality of CNG in a manner similar to the standards that are in place for liquid fuels to ensure that the emissions from CNG vehicles are consistently low.
- The gaseous fuels mainly, LPG, will see growth in major cities in the interim period as a substitute for petrol to check the growth of CNG which adversely affect the refining margins. This is a short-term fuel, which will be sold till matching Euro IV graded petrol and diesel is produced and sold.
- The growth of LPG will also be aided by the fact that major infrastructure is not necessary for the growth of LPG markets, a distinct advantage over CNG.
- The development of CNG markets will depend on the infrastructure, both for the transmission and distribution of natural gas and CNG, and the availability of natural gas.
- The automobile and oil industry should pursue vigorously with the government, the issue of credits for achieving lower emission norms and for introduction of technologies using renewable fuels etc. as is practiced in some developed countries.



Infrastructure and pricing issues related to fuels

Background

The Mashelkar Committee has pointed out that liquid fuels (petrol and diesel) will continue to have a very significant share in the transport sector. This is because improving their quality is more cost-effective approach compared to introducing alternative fuels in the transport sector. This conclusion also takes into account the refining and inland infrastructure already existing. The Committee recognizes the fact that CNG as an alternative fuel is possible in only those cities which are fed by natural gas pipelines and have the infrastructure for distribution. It has also pointed out that limited domestic availability of LPG means a dependence on imports, which would imply higher costs for import terminals and inland infrastructure. Meanwhile gaseous auto fuels have been introduced in Delhi and Mumbai, as these are cleaner than the best quality liquid fuels currently available.

With fuel quality standards becoming progressively more stringent, the investments required for producing better fuel in some refineries is more than that needed in others, which already use advanced refining technologies. While it is recognized that the maximum emission benefits of Euro IV fuels would accrue only with Euro IV vehicle technology, in cities with critical pollution levels the earlier phase-in of Euro IV fuel quality would also yield significant benefits with current vehicle technology. Indications from SIAM are that by 2007/08, Euro IV vehicles (other than 2-and 3-wheelers) can be introduced in the country.

The marketing of liquid transport fuels has been largely deregulated since 1 April 2002. This development will, in due course, have a significant impact on pricing and quality of the transport fuels sold by the oil-marketing companies. The deregulated market allows private and multinational companies to set up marketing networks in the country subject to certain entry norms. Recently, the government has agreed to modify the export-import policy that would allow imports of transportation fuels by private companies. Thus competition would no longer be confined to domestic boundaries.

The chapter provides an overview of the production and distribution infrastructure of liquid and gaseous fuels and factors affecting their pricing, based on the current taxation structure.

Liquid fuels

Refinery upgradation and production

The Mashelkar Committee recommended a roadmap for vehicular emission norms for auto vehicles where the entire country will move gradually from Bharat Stage II to Euro III and finally to Euro IV for 11 identified cities^a by the year 2010. The Committee has also identified refineries which can upgrade their facilities to produce these fuels at a relatively lower cost compared to other refineries because of their level of technical sophistication.

The following refineries which already have a catalytic reformer unit, a catalytic cracking unit and a hydrocracking unit are in the best position to meet future specifications for both petrol and diesel with minimal investments for post treatment:

- IOC Gujarat
- IOC Mathura
- IOC Panipat
- BPCL Mumbai (hydrocracker unit will be installed by 2004).

In addition, the following refineries should also be able to meet future specifications at a lower incremental cost than others because of the presence of a hydrocracking unit or a relatively high level of sophistication:

- NRL – Numaligarh
- MRPL – Mangalore
- RPL – Jamnagar

Apart from Kolkata, all the other 10 identified cities are within the economic supply zone of the above refineries.

It is TERI's view that these refineries should be directly upgraded to produce Euro IV fuels by 2006/07 instead of a phased introduction to Euro III and then to Euro IV by 2010 for the following reasons:

- a) Despite the heavy cost of phase-wise upgradation, as assessed in the Mashelkar Committee report, direct upgradation from Euro II to Euro IV

^a The Mashelkar Committee marks out 11 cities namely Delhi, Kolkata, Mumbai, Chennai, Hyderabad, Ahmedabad, Surat, Pune, Bangalore, Kanpur, and Agra for stricter standards due to the high levels of pollution in these cities.

will be, overall, more cost effective and allow refineries to better optimize the process units, utilities etc.

- b) As already pointed out, the earlier phasing in of Euro IV fuel quality would yield significant benefits even with current vehicular technology.
- c) Refineries in Japan, Korea, Taiwan, Thailand, Australia and Singapore are targeting to produce Euro IV fuels by 2006/07. Given the current self sufficiency in India's refining capacity which is likely to continue, with expansion of existing refineries and possibly one or more grassroots refineries, there will be instances where slack demand will require refineries to export petrol, diesel and other fuels or cut down on overall production. Indian refineries will therefore need to match specifications with other refineries in the Asia-Pacific region to remain competitive on the export front.

The transportation infrastructure

Liquid fuels are transported from refineries and coastal terminals to inland terminals and depots by pipeline, by rail and road. A vast infrastructure has been developed over the past 60–80 years. Table 6.1 provides a list of existing product pipelines and Table 6.2 the pipelines proposed by Petronet India Ltd.

Table 6.1 Existing produce pipelines

Company	Name	Capacity (MMTPA)
IOC	Barauni-Kanpur	1.80
IOC	Guwahati-Siliguri	0.82
IOC	Haldia-Barauni	1.25
IOC	Haldia-Mourigram-Rajbandh	1.35
IOC	Koyali-Ahmedabad	1.10
IOC	Mathura-Jullunder	3.70
IOC	Kandla-Bhatinda	7.50
IOC	Digboi-Tinsukia	0.73
HPCL	Mumbai-Pune	3.67
HPCL	Vizag-Vijaywada-Secunderabad	4.10
BPCL	Mumbai-Manmad	4.33
Petronet	Vadinar-Kandla	11.50
Petronet	Kochi-Karur	3.30
GAIL (LPG only)	Jamnagar-Loni	1.70
Total		46.85

Table 6.2 Proposed pipelines by Petronet India Ltd. (PIL)

Pipeline	Sponsors	Design capacity (MMTPA)
Mangalore-Hassan-Bangalore Pipeline	PIL, HPCL, Financial institutions	5.6 + 8.5*
Chennai-Trichy-Madurai Pipeline	PIL, IOCL, Financial institutions	2.0 + 2.5*
Bina-Jhansi-Kanpur	PIL, BPCL	3.0
Paradip-Jatni-Rourkela	PIL, IOC	5.0
Central India Pipeline	PIL, IOC, RPL, BPCL, EOL	4.0 + 9.5*

* Future expansion

All these pipelines, apart from the Jamnagar Loni pipeline by GAIL, are meant for petrol, high speed diesel and other white products. Of the 11 cities, two are refinery locations (Mumbai and Chennai) and all the others are supplied by pipeline or are in close proximity to pipeline tap-off points. This makes the supply of transportation and other fuels to these cities convenient, assured, and environmentally safe. In addition, all the oil companies have an extensive network of retail outlets in the cities and a total of over 19,000 retail outlets across the country.

Upgrading the quality of a fuel in a particular market will not require any addition or change in the infrastructure but more quality control measures will need to be put in place.

Pricing issues

The government announced the deregulation of petroleum product prices w.e.f. 1 April 2002. In effect, this has allowed the oil companies to set their own prices based on the import parity concept and introduced a degree of competition in the market. While the Ministry of Petroleum and Natural Gas maintains that revision of prices is in the hands of oil companies, in practice the Ministry continues to control the level at which prices are set, and this was most evident in the build up to the war in Iraq, when despite spiralling crude oil prices, oil companies were not permitted to raise product prices. The Petroleum Sector Regulatory Bill which was introduced in Parliament in 2002, does give the freedom to oil companies to set market determined prices but this can only take place once the Bill is passed, a truly independent regulatory authority is appointed and government disassociates itself, both by word and by deed, from the pricing process.

Earlier the subsidies on LPG and kerosene were met by a heavy tax on petrol and aviation fuel and this cross subsidy was routed through the oil pool accounts maintained by the Oil Coordination Committee. With effect from 1 April 2002, the oil pool accounts were closed and the subsidies are being

provided directly in the Union Budget. However, the high duties on petrol still remain. A reference to Annex 6.1 shows that the differential of around ten rupees per litre between the prices of diesel and petrol is almost entirely due to the additional excise duty on petrol of seven rupees per litre and the cascading effect on ex-retail outlet prices.

Considering the oil industry's very large contribution by way of excise and other duties to the resources at the disposal of the government, it is unlikely that the duty element on petrol will be reduced and the differential between petrol and other products will thereafter continue. However, a move has been made to reduce the subsidy on LPG and kerosene and it remains to be seen whether the government can overcome political compulsions and substantially reduce the subsidies in the next two budgets and completely phase them out thereafter.

In the Union Budget 2003, it proposed to introduce a value added tax (VAT) regime to eliminate the cascading effect of duties and also to bring about uniformity in the sales tax structure in different states. However, petroleum products have been excluded for two years. Therefore the cascade effect in the price of petrol, in particular, will remain.

Effect of ethanol-blending mandate on petrol price

With effect from 1 January 2003, ethanol blending in petrol to the extent of 5% has been made mandatory in nine states and four union territories. This could have an impact on the price of petrol and could also lead to price distortions between different places within the same state and across different states. The main reason for this is that the ethanol price and issues related to ethanol supply will not be under the control of the oil industry. Issues such as cartelization by ethanol suppliers to increase the ethanol price cannot be ruled out.

As provided in Budget 2003, the excise duty on gasohol is lower by 75 paise per litre compared to petrol. This incentive, ethanol producers say, is not enough. It may become necessary for the government to announce a higher incentive to sustain the ethanol-blending mandate.

The price of petrol with ethanol prices at the depot level at 14.3 rupees per litre and 15.5 rupees per litre does not result in an increase in the price of petrol with the current excise exemption of 75 paise per litre, but any withdrawal of the incentive or a higher ethanol price would result in an increase in petrol prices (see Annex 6.1).

Gaseous fuels

The gaseous fuels considered are CNG and LPG. These fuels are vastly different in terms of their pricing and also transportation and distribution constraints.

CNG

India's consumption of natural gas has risen faster than any other fuel over 1995-2001, mostly due to increased usage in power generation and in fertilizer production. The total natural gas consumption in the country was 28.04 BCM in 2001/02 of which 65% was used for generating energy. The Tenth Five Year plan has projected the natural gas demand at 47.45 BCM as against a production potential of 37.62 BCM in the year 2006/07. The gas demand is expected to rise to 64 BCM by 2011/12. Despite the recent find by Reliance Industries of 196 BCM of substantial reserves of gas in the Krishna Godavari (KG) basin, capable of sustaining a supply of 14 BCM annually, domestic supply is unlikely to keep pace with demand.

To meet the current and future shortfall there are plans to import gas by the following means:

- By pipelines from neighbouring countries such as Bangladesh, Iran etc
- As liquefied natural gas (LNG) from the Middle East etc.

Between the two options presented above, the second option is the more likely as it does not involve any geo-political issues. Terminals will need to be built to regasify the LNG. The planned terminals are listed below:

- Petronet LNG terminal at Dahej, Gujarat (5.0 MMTPA)
- Shell LNG terminal at Hazira, Gujarat (2.5 MMTPA)
- Dabhol LNG terminal at Dabhol, Maharashtra (3.0 MMTPA)
- Petronet LNG terminal at Kochi, Kerala (2.5 MMTPA)
- IOC LNG terminal at Kakinada, Andhra Pradesh (2.5 MMTPA)

The Dabhol plant is essentially complete but is closed. The Hazira and Dahej terminals are under construction but they have yet to enter into firm 'take-n-pay' contracts with customers. The other plants are unlikely to materialize particularly in view of the Reliance Industries gas find.

Infrastructure development

Currently, the Western offshore accounts for 60% of India's production of natural gas. Offshore gas is brought onshore at Uran in Maharashtra and Hazira in Gujarat, where it is sweetened and fed into the HBJ (Hazira-Bijaipur-Jagdishpur) 2300 km pipeline system which traverses the following states:

- Gujarat
- Madhya Pradesh
- Rajasthan
- Haryana
- Uttar Pradesh, and
- Delhi.

There are a number of fertilizer and power plants along this route.

There are no other cross-country gas pipelines but small regional networks supply gas directly to some bulk consumers. These grids are not suitable for gas distribution networks. GAIL is by far the largest distribution company in India. It plans to expand the capacity of the HBJ pipeline from the current levels of 33.4 MMSCMD to 60 MMSCMD (www.gail.nic.in, 17 September 2002) to cater to the increased availability of gas from LNG plants in Gujarat. If a gas supply from Bangladesh fructifies, this could be fed into the northern region by a pipeline traversing West Bengal, Bihar and UP. Similarly the Reliance gas find in the KG basin could see the start of a southern gas network and the makings of a national grid.

Existing distribution infrastructure for CNG in cities

An established distribution infrastructure is available only in Mumbai, Surat, Ankleshwar, Baroda, and Delhi. When Delhi faced a shortage of gas, the Supreme Court directed that the transport sector be given the highest priority. Gas supplies to Maruti Udyog at Delhi, Reliance and Essar at Hazira, Gujarat were curtailed to increase the gas supply to Delhi. This approach may also be followed in other places where there is a demand-supply gap.

On 5 April 2002, the Supreme Court of India, inter alia, passed the following order:

“The Union of India will give priority to transport sector including private vehicles all over India with regard to the allocation of CNG. This means that first the transport sector in Delhi, and in the other air polluted cities of India, CNG will be allocated and made available and it is only thereafter if any CNG is available, that the same can be allocated to the industries, preference being shown to public sector undertakings and power projects”.

This however, presupposes that a gas transmission system already exists or is justified in terms of a suitable anchor load by the power and fertilizers sectors from which the CNG distribution systems can be developed as an extension.

Thereafter it would be possible to give CNG priority over other sectors. It would not be economical to lay a long distance transmission lines only to meet CNG demand. Therefore, the growth of a CNG network will depend on the growth of the transmission network for the power fertilizer and industry sectors. Supplying CNG to the transport sector would also require additional gas compressor stations and dedicated CNG outlets. This would necessarily take time and involve considerable expense as land in big cities is difficult to obtain and costly.

Pricing of natural gas

The Union Cabinet decided in 1997 to raise gas prices in phases to parity with the international prices of fuel oil by 2002. However domestic gas is currently capped at 2850 rupees/MCM (1.71 dollars/MMBtu) at the supply source or 2.45 dollar/MMBtu in Delhi which is approximately 50% of fuel oil parity. Any raising of price would have an adverse impact on the power sector (where the price of fuel is a pass through) and in the fertilizer sector (which would require the government to increase the subsidy to fertilizer units). According to a recent news item, GAIL due to several cost cutting measures is in a position to price regasified LPG in Delhi at around 3.6 dollars/MMBtu. If domestic prices are not raised, in order that users of regasified LNG are not discriminated against, it may become necessary to introduce a pooled gas price similar to the pooling system for indigenous and imported crude oil that existed before 1 April 2002. A comparison of CNG, imported, and indigenous prices based on fuel oil parity is given in Annex 6.2.

LPG

Domestic LPG is sourced from refineries (68%) and by separation from natural gas (32%). Any shortfall in demand is made up by imports. Supplies are mainly to the domestic market (82%) with the balance to commercial and industrial sectors. Till recently there were long waiting lists in the domestic sector due to the expanding base of the market and unfilled demand. However, arising from increased domestic production both from refineries and natural gas units, and aided by imports, LPG for domestic use is now readily available. LPG sales in the year 2001/02 were 7.7 MT.

Infrastructure

India has a well diversified network of domestic LPG sources and a total of 203 LPG bottling plants (each with its own bulk storage facility) spread across the

length and breadth of the country. LPG is transported in pressurized tankwagons and tanklorries to the bottling plants where cylinders are filled and then distributed by road to individual customers. To meet the shortfall between supply and demand, import terminals were initially set up in Mumbai and Vishakapatnam by the public sector oil companies. Later, facilities were put up at Mangalore and Kandla (cryogenic storage) also by the PSUs. To evacuate the large LPG production from the Reliance refinery and imports at Kandla, GAIL has constructed a long distance dedicated LPG pipeline to Loni in UP. GAIL is also laying a pipeline from Vishakapatnam via Vijayawada to Secunderabad to be completed by December 2004 (www.gail.nic.in, 17 September 2002). IOC is constructing an import terminal at Haldia. In addition, various parallel marketers have small terminals at various coastal locations, not all of which are operative.

Till recently, because of unsaturated domestic demand, LPG was not being released for automotive use. The government has now allowed its use and has also qualified agencies to provide cylinders and conversion kits, costing around 30,000 rupees. Unlike CNG, a very well established LPG distribution system already exists in the form of transportation infrastructure and the storage capacities at bottling plants. In addition LPG mounted storage and LPG dispensing units can be installed at existing retail outlets (observing the requisite safety distances) and supplied bulk LPG by the same type of pressurized tank-lorries that currently feed the bottling plants.

However growth is expected to be slow as:

- a) Vehicle manufacturers are yet to provide factory-fitted cylinders and conversion kits.
- b) A number of cars operate illegally on domestic cylinders/gas and conversion kits costing around 4000 rupees. Besides domestic gas is subsidized which will not be the case with auto LPG. This trend could continue even after auto LPG is introduced.

Pricing issues

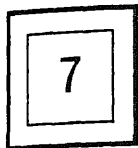
The major advantage that auto LPG currently has over petrol is the lower level of taxes.

Transportation and storage costs of LPG are higher than those for liquid fuels. Also import of LPG entails significant ocean freight costs. If taxation levels are changed, there could be a significant increase in prices compared to petrol.

The indicative price build-up of auto LPG is given in Annex 6.3.

Conclusions

- To enable the government to implement the Supreme Court's directive to give priority to transport sector including private vehicles all over India with regard to the allocation of CNG, the gas distribution network must first be put in place. This in turn will require a transmission system that has its anchor load in the power and fertilizer sector plus sufficiently long-term availability of gas at a competitive price. Setting up the distribution and retail network for CNG will be therefore be time consuming and expensive.
- LPG has the advantage over CNG of an existing, well established and extended distribution network and auto LPG can be sold through the existing large petrol and diesel retail outlet network. A stable price regime which will enable vehicle owners to recoup their investment in the LPG cylinder/ conversion kit and a strict enforcement of a ban on using domestic LPG/cylinder will be necessary for auto LPG viability.
- In the case of petrol and diesel both the distribution and retail infrastructure already exist. Refineries will need to make considerable investments to upgrade fuel quality which will require government incentives. Increased competition between companies and export market competitiveness should hasten the process.



Emission control technologies for internal combustion engines

Introduction

Vehicle exhaust emissions can be lowered by reducing engine out emissions, by improving the combustion process and fuel management, or by changes to the type of fuel or its composition. Many changes in basic engine design have also greatly reduced engine out emissions, but reaching Euro IV levels would require post-combustion control technologies also. Emission control technologies—autocatalysts, hydrocarbon adsorbers and particulate filters—in combination with good quality fuels (such as unleaded gasoline, low sulphur gasoline, diesel) and enhanced engine management reduce emissions to very low levels. These applications may emerge as new engine designs or in retrofitted engines.

This chapter reviews the post combustion emission control technologies (ECTs) available and the role of fuel quality in ensuring their success. Almost all commercial ECTs available today are based on the oxidation properties of the platinum group of metals (PGMs) including platinum, rhodium, and palladium.

This chapter is divided into two parts. Part 1 presents an overview of the current technology using catalysts for emission control commercially available. Part 2 deals with the emerging technologies for stoichiometric and lean burn combustion.

Current technology for emissions control using catalysts

Catalyst-equipped cars were first introduced in the USA, Canada, and Japan in 1974. Other countries, including South Korea, Australia, Singapore, Sweden, and Switzerland, followed and catalyst-equipped cars appeared on the European roads from 1985. Many other countries, including India, have also found that catalytic converters are the most effective way of dealing with the growing problem of air pollution. In 1993, the European Union set new car emission standards that effectively mandated the installation of emission control three-way catalysts on petrol-fuelled cars. Now more than 300 million of the world's 500 million or so cars, and over 85% of all new cars produced worldwide are equipped with autocatalysts (Searles and Bosteels 2003). Catalytic converters are also fitted on heavy-duty vehicles, motorcycles, and other vehicles.

Autocatalysts

Two-way oxidation catalysts convert CO and HC to CO₂ and water, and decrease the mass of diesel particulate emissions but have little effect on NO_x. The three-way catalysts (TWC) operate in a close loop system and include a lambda- or oxygen sensor to regulate the air-fuel ratio. The catalyst can then simultaneously oxidize CO and HC to CO₂ and water, while reducing NO_x to nitrogen. These simultaneous oxidizing and reducing reactions have the highest efficiency in the small air-to-fuel ratio window around the stoichiometric value, when air and fuel are in chemical balance.

Diesel oxidation catalysts

These are two-way catalysts, which are used primarily to reduce CO and HC emissions from diesel engines. The NO_x emissions from diesel engines are very high relative to spark ignition engines and hence three-way catalysts have not been developed. The catalysts used for oxidation are not capable of reducing NO_x emissions significantly due to higher engine out NO_x emissions, and different formulations are required.

To understand devices used to reduce particulate matter it is important to first understand the composition of the particulate matter. This is elaborated in Annex 7.1. A diesel oxidation catalyst is expected to reduce the soluble organic fraction (SOF) of diesel particulate matter by up to 90% (Horiuchi, Makoto et al., 1990). This is important because the SOF portion contains numerous chemicals of concern to health experts. The SOF fraction which mainly comprises PAH and unburnt fuel gets oxidised in a diesel oxidation catalyst (Lox 1991). Control of SOF enables the oxidation catalyst to reduce the total particulate emissions by 25% to 50%, depending its constituents (Horiuchi, Makoto et al., 1990). This technology also reduces diesel smoke eliminates the pungent odour of diesel exhaust and significantly reduces CO and HC. However, the number of particles is unchanged and issues associated with the effects of ultrafine particulates are unresolved. Diesel Oxidation Catalyst (DOC) technology has been successfully used on all diesel cars sold in Europe since 1996 but not many heavy-duty vehicles have been equipped with it (Voss, et al., 1997).

Two-way DOCs have already been commercialized and are in use in some categories of vehicles in India. The DOCs also reduce particulate matter in the exhaust gases by 25%–30% as the DOCs oxidize the soluble organic fraction (SOF) of the particulate matter. The SOF forms 25%–40% of the particulate matter emissions from diesel engines (Tanaka, 1998). The DOCs can be used

with the current quality of diesel (max 500ppm S) sold in Delhi, Mumbai, Kolkata, and Chennai.

The catalysts used in the DOCs are usually made of platinum or rhodium or a combination of the two. There are some design considerations that should be carefully studied before using this technology:

- Some loss of engine power will be expected due to the fitment of a device on the exhaust pipe which would restrict the flow of exhaust gases.
- The design device should take the hydraulics for flow into account.
- This can be accomplished by using a substrate (the base on which the precious metal is present as active sites) which has a higher open surface area so as to reduce restrictions to flow of the exhaust gases.

The number of active sites per unit area of substrate (cells), precious metal quantity, must be optimized in order to minimize the cost of the device. The reduction in PM is in the range of 20%–50% (average of about 30% can be considered as practically possible), CO and HC reduction efficiencies are high at 90%. (www.dieselnets.com/mdec/1999/mckinnon.pdf, 25 August 2002)

Since the reduction in PM is very limited these devices will not be useful for achieving the PM level of 0.01 g/bhp-hr (2007 US PM regulation) or even Euro IV emission levels. Other technologies will be required to achieve these levels of PM. Very active catalysts used with high levels of sulphur in the diesel could result in an increase in PM emissions as sulphate formation increases with the conversion of sulphate from SO₂ in the diesel exhaust, thereby competing with the reactions of reduction of CO and HC.

Substrate technology

There has been great progress in research on catalyst substrates. In 1974, ceramic substrates had a density of 200 cells per square inch (cpsi) of cross section (31 cells/square cm) and a wall thickness of 0.012 inch or 12 mil (0.305 mm). By the end of the 1970's the cell density had increased through 300 to 400 cpsi and wall thickness had been reduced by 50% to 6 mil (0.153 mm).

Now 400, 600, 900, and 1200 cpsi substrates are available and wall thickness can be reduced to 2 mil – almost 0.05 mm (Searles and Bosteels 2003). In the late 1970s, substrates derived from ultra thin foils of corrosion resistant steels came onto the market. In the beginning the foils could be made from material only 0.05 mm thick allowing high cell densities to be achieved. Complex internal structures can be developed and today wall thickness is down

to 0.025 mm and cell densities of 800, 1000, and 1200 cpsi substrates are available (Searles and Bosteels 2003).

This progress in ceramic and metal substrate technology has major benefits. A larger catalyst surface area can be incorporated into a given converter volume and this allows better conversion efficiency and durability. The thin walls reduce thermal capacity and avoid the penalty of increased pressure losses. Alternatively, the same performance can be incorporated into a smaller converter volume, making the catalyst easier to fit close to the engine, as cars get more compact.

New technologies for emissions control for stoichiometric combustion

Hydrocarbon adsorbers

Hydrocarbon adsorber systems incorporate special materials, such as zeolites, into or upstream of the catalyst. Hydrocarbon emissions are collected when exhaust temperatures are too low for effective catalyst operation. The hydrocarbons are then desorbed at higher temperatures when the catalyst has reached its operating temperatures and is ready to receive and destroy the hydrocarbons. This technology has the potential to reduce hydrocarbons to less than half the levels emitted from a three-way catalytic converter (Noda, et al , 1998).

New technologies for emissions control for lean combustion

With the development of lean burn direct injection gasoline engines and increased use of diesel engines, the challenge for automotive catalysts for lean combustion is to limit CO₂ emissions and reduce fuel combustion. New diesel technologies with electronic management and direct injection can achieve further fuel consumption improvements. Conventional three-way catalyst technology used on petrol engines needs a richer environment with lower air-fuel ratios to reduce NO_x so a radical new approach is required.

DeNO_x catalysts and NO_x traps

The following four systems are being evaluated by industry to reduce NO_x emissions:

- Passive DeNO_x catalysts using reducing agents available in the exhaust stream
- Active DeNO_x catalysts using added hydrocarbons as reducing agents
- NO_x traps or adsorbers used in conjunction with a three-way catalyst

- Selective catalytic reduction using a selective reductant, such as ammonia from urea.

DeNO_x (or Lean NO_x) catalysts

DeNO_x catalysts use advanced structural properties in the catalytic coating to create a rich 'microclimate' where hydrocarbons from the exhaust can reduce the nitrogen oxides to nitrogen, while the overall exhaust remains lean. Further developments focus on increasing the operating temperature range and conversion efficiency.

This is a well-established technology and has already been commercialized in Europe and the US. There are two types of catalysts, passive and active. Both types are discussed below.

DeNO_x catalyst (passive)

This technology can be used both for light and heavy-duty applications. The technology uses the exhaust hydrocarbons as reducing agents to convert the NO_x to nitrogen gas. It is very similar in this aspect to the gasoline three-way catalytic converter, which also uses similar reaction mechanisms to reduce NO_x.

The reduction obtained in the NO_x levels is in the range of about 5%–20% (Johnson 2000 and 2001). The main advantage of this technology is the low complexity of implementation and its small impact on the engine.

Some disadvantages of this technology are listed below:

- Low levels of NO_x conversion efficiency due to lower hydrocarbon selectivity.
- The exhaust will have to be enriched with hydrocarbons for improving the conversion efficiency.
- In case of heavy-duty applications, the catalyst is active above 350° C.
- The moisture stability of the catalyst is poor and the catalyst is also sensitive to SO₂ leading to high sulphate formation.
- Low sulphur fuels required for better activity of the catalyst.

The effect of these catalysts on fuel consumption is not clear.

Typical catalyst formulations currently in use are given below:

- Platinum/Al₂O₃ for a temperature range of 200 to 300°C
- Zeolite based catalysts (Cu/ZSM-5) for temperatures greater than 350 °C.
- Special oxides of titanium for temperatures range between 300 and 350° C.

In many cases a combination of low temperature and high temperature catalysts is used for higher conversion efficiency.

For temperatures lower than 150° C, there are no technologies currently available. In cases where such low temperatures exist, a NO_x trap is used which stores NO_x until the temperature reaches 200° C for the reaction to start.

DeNO_x catalyst (active)

The conversion efficiencies in this case are in the range of 15% to 35 %, which is higher than observed in the previous case (Johnson 2000 and 2001). In this case having an in-cylinder post injection HC enrichment or enrichment in the exhaust enriches the exhaust gases with hydrocarbons. There would be an increase in fuel consumption to the extent of about 1%.

There are some disadvantages of this technology, which need to be noted:

- Narrow temperature range of activity.
- A small increase in fuel consumption.
- Slight increase in HC emissions and possibility of requiring an oxidation catalyst to reduce the HC emissions.
- Fuels with low sulphur levels are required in order to reduce sulphate formation on the catalyst.

The catalyst formulations are same as the formulations for the passive type catalyst.

NO_x adsorbers (or lean NO_x) traps

NO_x traps are a promising development as results show that NO_x absorber systems are less constrained by operational temperatures than DeNO_x catalysts. NO_x traps adsorb and store NO_x under lean conditions. A typical approach is to speed up the conversion of nitric oxide (NO) to nitrogen dioxide (NO₂) using an oxidation or three-way catalyst mounted close to the engine so that NO₂ can be rapidly stored as nitrate. Developments and optimization of NO_x adsorber systems have been and are currently underway for diesel and petrol engines. These technologies have demonstrated NO_x conversion efficiencies ranging from 50 to in excess of 90 percent depending on the operating temperatures and system responsiveness, as well as fuel sulphur content (Luders, Stommel and Geckler 1999; Ruzicka and Liebscher 1999). The system is in production with direct injection petrol engines.

DeNO_x – selective catalytic reduction (SCR) – urea agent

This technology has received the maximum attention due to the significant reduction potential of NO_x to the Euro IV emissions regulations. SCR technology permits the NO_x reduction reaction to take place in an oxidising atmosphere. It is called 'selective' because the catalytic reduction of NO_x with ammonia (NH₃) as a reductant occurs preferentially to the oxidation of NH₃ with oxygen. Several types of catalyst are used, the choice of which is determined by the temperature of the exhaust environment. For mobile source applications the reductant source is usually urea, which can be rapidly hydrolyzed to produce ammonia in the exhaust stream.

The technology is based on the injection of urea as an aqueous solution into the exhaust gas before the catalyst with an air assisted injection nozzle. The urea reacts with NO_x to form nitrogen gas, water, and carbon dioxide. The catalyst is based on metal oxides like vanadium pentoxide (V₂O₅), titanium dioxide (TiO₂) and tungsten trioxide (WO₃). The optimum operating temperature range is 250 to 500° C. The conversion of the catalyst is higher for NO₂ than for NO so there is an oxidation catalyst upstream of the SCR catalyst which converts the NO to NO₂ (Johnson, 2001).

This technology is not yet fully commercialized though there are many technology demonstration projects, which are currently underway in Europe and the US. Also the focus of this technology is for heavy-duty applications.

The Low Emission Vehicle II and Euro V legislation in 2007/08 require a high conversion level of nitrogen oxides to meet the emission standards for diesel trucks and other diesel vehicles. Therefore, US and European heavy-duty diesel engine manufacturers are considering the introduction of urea SCR systems no later than 2005. The catalysts used currently in the SCR systems are based mainly on systems derived from stationary power plant applications for nitrogen oxide reduction. New catalysts are being developed for achieving high conversion levels for nitrogen oxides. Synthetic zeolite based catalysts (molecular sieves) are the latest developments in this field (Gieshoff 2001).

The main advantages of this technology are given below:

- High conversion efficiency of about 60 to 90 %.
- Will help in heavy-duty engine compliance with Euro IV norms.
- No increase in PM emissions unlike the technologies which have been described before.
- There are studies, which suggest sulphur tolerance of this technology, though all current test and demonstration projects are with very low sulphur diesel.

This technology also has some disadvantages, which are important from the commercialization viewpoint.

- Urea injection equipment and tank for urea storage required.
- Possible slip of ammonia with exhaust gases which would require another oxidation catalyst downstream to contain.
- Infrastructure will be required for refilling urea in the urea tanks of the vehicles.
- Though the SCR catalyst is not sensitive to sulphur, a reversible ammonia-sulphate formation at high levels of sulphur in diesel would require the use of low sulphur fuels to avoid the formation of sulphates in the SCR catalyst.

There will be no perceived impact on fuel consumption directly. Due to the packaging problems and high costs, this technology can be used mainly for heavy-duty applications and its use in light-duty applications will not gain ground due to the high cost of the technology. Table 7.1 compares the reduction in NO_x from a baseline using the technologies stated above (CONCAWE 1999).

Table 7.1 Comparison between different NO_x reduction technologies

Technology	Fuel sulphur level (max wt-ppm)	% reduction from baseline
Exhaust Gas Recirculation (EGR)*	No limit on fuel sulphur	30 - 45
DeNO _x catalyst (passive)	500	5 - 20
DeNO _x catalyst (active)	500	15 - 35
Selective catalytic reduction (SCR)	50 (even less for more reduction)	60 - 90

*EGR can be used in conjunction with any of the other three technologies stated above to get a combined effect of more reduction in NO_x.

Diesel particulate filters (DPF)

DPF systems consist of a filter material positioned in the exhaust designed to collect solid and liquid particulate matter (PM) emissions while allowing the exhaust gases to pass through the system.^a A number of filter materials are used, including ceramic monoliths, woven silica fibre coils, ceramic foam, wire mesh and sintered metal. Collection efficiencies of these filters range from 50% to over 90%, but most filters today are designed to achieve a 90% or greater level of particulate control in terms of mass, but over 99% when expressed as numbers of ultrafine particles. A study has found that advanced filter technology almost completely eliminated the fine, carbon particulate in the size range of less than 100 nm diameter with an efficiency of >99% (Mayer *et al.* 1998). This is very

^a The components of the particulate matter namely carbon soot, sulphates and nitrates and soluble organic fraction (SOF) derived from fuel and lubricating oil, are described in Annexure 7.1.

important since health experts believe that it is the fine particulate that is carried deep into lungs and is thought to be the most dangerous size of PM. More details on DPF are presented in Annex 7.2.

Since the wall flow filter would readily become plugged with particulate material in a short time, it is necessary to 'regenerate' the filtration properties of the filter by burning off the collected particulate matter on a regular basis. To achieve regeneration of the collected PM by oxidation or combustion with a DPF without any additional activation mechanism, the collected particulate matter in the filter must attain a minimum temperature in the range of 600 to 650° C in order to auto-ignite and sustain combustion. The most successful methods to initiate and sustain regeneration include:

- Incorporating a catalytic coating on the DPF to lower the temperature at which particulate matter burns.
- Using very small quantities of fuel-borne catalyst (see Annex 7.2 for its details), such as cerium oxide. The catalyst, when collected on the DPF as an intimate mixture with the particulate, allows the particulate to burn at normal exhaust temperatures to form carbon dioxide and water, while the solid residues of the catalyst are retained on the DPF (Zelenka, et al. 1998).
- Incorporating an oxidation catalyst upstream of the DPF that, as well as operating as a conventional oxidation catalyst, also increases the ratio of NO₂ to NO in the exhaust. Trapped particulates burn off at normal exhaust temperatures using the powerful oxidative properties of NO₂ (Hawker et al. 1998).
- Electrical heating of the DPF either on or off the vehicle, which would allow simple regeneration but impose a fuel penalty.
- A combination of above mentioned systems and intelligent engine-management allows efficient regeneration under all operating conditions. The first diesel passenger car equipped with a combined filter system was commercialized in 2000. Recent evaluations indicate a good and durable performance (Salvat *et al.* 2000).

Continuously regenerating DPFs are very successful in retrofit applications of older heavy duty diesel vehicles and buses in various regions over the world. The real world durability of these systems is proven every day in major cities in Europe and the US (Allansson et al. 2000; Lanni et al. 2001; Voss et al. 2000).

The cost effectiveness for PM reduction for DPF is in the range of about 2500 to 6000 dollars/metric tonne (MECA 1999). The particulate matter abatement

cost is a function of the regeneration technology that has been used in the filter. The cost is higher for catalyst-based technologies. The durability (filter life and maintenance schedule) of the filter plays an important role in determining the cost of the particular PM reduction technology.

This technology appears to be cost-effective and will compete in terms of cost/tonne of PM abatement with other established technologies in the future. Tests need to be done in the Indian context with this technology for ascertaining its impact. There are many similar products provided by many leading fuel additive companies such as the Octel Corporation, Ethyl Corporation and Lubrizol Corporation with iron, manganese and copper-based additives, respectively for catalyzing filter regeneration. Table 7.2 compares different particulate control technologies (Johnson 2000). It is also important to note that the emission benefits are very closely related to the duty cycles using which these engines are tested. The results of another study presented in Table 7.3 give a comparative analysis of different PM control technologies based on a bus experiment in New York using the Central Business District Driving Cycle. (www.epa.gov/otag/retrofit/documents/ny_crt_presentation.pdf, 13 September 2002).

Table 7.2 Comparison between different particulate control technologies

Technology	Diesel fuel sulphur (wt-ppm)	% Reduction from baseline
Baseline (only EGR*)	368	Baseline
Baseline	54	13
Baseline + FBC	368	26
Baseline + FBC + DOC	368	33
Baseline + DPF ⁽¹⁾	368	82
Baseline + CRT (Johnson Matthey)	54	86
Baseline + FBC + DPF ⁽²⁾	368	96

EGR – Exhaust Gas Recirculation (see Annex 7.1 for details)

FBC – Bimetallic Platinum / Cerium Fuel Borne Catalyst

DOC – Diesel Oxidation Catalyst

CRT – Continuously Regenerating Trap (equivalent to DOC + DPF)

DPF ⁽¹⁾ – Catalysed Diesel Particulate Filter

DPF ⁽²⁾ – Uncatalysed Diesel Particulate Filter

Diesel Engine Type – Detroit Diesel Series 60 Engine

Table 7.3 Comparison of different diesel emission control technologies on PM₁₀ emissions

Technology	Diesel fuel sulphur (wt-ppm)	PM emissions
OEM catalytic muffler*	350	Baseline
OEM catalytic muffler	50	35
OEM + CRT	50	94

*Catalysed Muffler is equivalent to a diesel oxidation catalyst

Combined emission control systems (DPF+SCR)

The stringent emission limit values of NO_x and PM for heavy duty diesel (HDD) engines in 2005 and 2008, and health concerns about the emission of ultra fine particles into the atmosphere would require a combined emission control system that would include a urea-based SCR system and DPFs with appropriate regeneration in the new generation HDD engines.

DPFs combined with SCR systems show significant reduction of both NO_x and particulate matter (Khair et al. 2000 (a); Khair et al. 2000 (b); Chandler. et al. 2000-01). With any catalyst/DPF combination including a precious metal, the use of diesel fuel with sulphur lower than 10 ppm is necessary to keep the formation of sulphate particulates within future legislated limits (Allansson et al. 2000). Sulphur is also responsible for sulphate deposits on the DPF surface that can cause an increase of exhaust gas backpressure requiring more frequent regeneration, increasing of fuel consumption and CO₂ emissions. To avoid this, sulphur-free fuel (<10 ppm) is required.

Evaluation of emission control devices in heavy-duty diesel engines

Emission control in heavy-duty diesel has been the focus of research many years due to its increasing use. PM and NO_x are the most critical pollutants from diesel engines and have a significant impact on human health. There is a general agreement in the literature that even with advances in engine technology, 'after treatment or emission control devices' and 'cleaner diesel (containing maximum 50 ppm sulphur level)' would be necessary to reduce emissions of fine particulates and oxides of nitrogen from diesel vehicles to acceptable levels. Recent field and laboratory trials on HDD vehicles in Europe and the USA suggest that advanced catalyst and trap systems, together with optimized engine management and emission controls will aid the achievement of the future low emission standards (Euro IV and beyond).

Europe

The European Union introduced the ETC (European transient cycle), together with the ESC (European stationary cycle) for emission certification of heavy-duty engines in Europe starting in the year 2000. The ESC and ETC cycles replace the earlier R-49 test cycle. The details of these European test cycles are given in Annex 7.3. New test cycles (ESC and ETC) and tougher emission standards for HDD vehicles have been introduced in 2000 and finalized for 2005. A HDD test programme demonstration has recently been completed with an Advanced Emission Control System at Ricardo Consulting Engineers, UK, using these two test cycles. The test results show that Euro V emission limits (set for 2008) can be met with a 50% safety margin with a catalyst-based diesel particulate filter (CB-DPF), a selective catalyst reduction system and a clean-up catalyst applied to a standard series production EU III engine, even after a severe ageing cycle including high sulphur fuel misfuelling (Searles et al. 2002; Andersson et al. 2002).

The ETC and ESC test results presented in Tables 7.4 and 7.5 reveal that the emission control system (CB-DPF + SCR + clean-up catalyst) gave a catalyst out NO_x level of below 1.0 g/kWh on ETC and ESC tests, corresponding to a reduction of 85% after 1000 hours ageing. NH₃ emissions were well below 10 ppm throughout the 1000 hours. The urea consumption was about 4.4% of the diesel fuel consumption over the durability test and 4.8% in the ESC and ETC tests (Searles and Bosteels 2003).

Table 7.4. HDD demonstration programme: test results under ETC

ETC [g/kWh]	2008 (Euro V) limits	Before ageing test		Conversion Efficiency [%]	After ageing test		Conversion efficiency [%]
		Engine out	Catalysts out		Engine out	Catalysts out	
HC	0.4	0.31	0.07	77	0.29	0.07	76
CO	3	0.8	0.03	96	0.78	0.01	99
NO _x	2	5.89	1.06	82	5.83	0.85	85
PM	0.03	0.066	0.01	85	0.064	0.011	83

Table 7.5. HDD demonstration programme: test results under ESC

ESC [g/kWh]	2008 (Euro V) Limits	Before ageing test		Conversion Efficiency [%]	After ageing test		Conversion efficiency [%]
		Engine out	Catalysts out		Engine out	Catalysts out	
HC	0.25	0.22	0.04	82	0.2	0.05	75
CO	1.5	0.5	0.03	94	0.53	0.01	98
NOX	2	5.27	0.89	83	5.26	0.8	85
PM	0.02	0.07	0.016	77	0.064	0.007	89

Particulate emissions were reduced by about 85% on both ETC and ESC tests after 1000 hours ageing. Exhaust backpressure remained constant throughout the ageing test, in spite of deliberate misfuelling with 250 ppm sulphur fuel for 100 hours. Particulate emissions contained virtually no carbon. Total particulate numbers were reduced by about two orders of magnitude (over a size range from 10 to > 100 nm). CO emissions were virtually eliminated by the catalysts; HC emissions were reduced by 75% (>85% when corrected for methane in ambient air).

USA

In 2000, the Air Resources Board (ARB) adopted a comprehensive Diesel Risk Reduction Plan to control emissions from all diesel engines in California. The goal of the plan is to reduce diesel PM emissions and the associated health risk by 75% in 2010 and by 85% in 2020. While the Plan encourages the use of alternative fuels such as CNG, the use of diesel fuel is not prohibited. The use of readily available retrofit technologies for existing diesel engines is enforced with incentives because fleet turnover by vehicle replacement is slow as a means to achieve near-term health benefits. It has been recognized that retrofit control technologies will require engine modifications and emissions after-treatment, such as a particulate filter and NO_x catalyst system. Moreover, to achieve optimal benefits from exhaust after-treatment, vehicles will also require the use of ultra-low sulphur diesel (containing less than 15 ppm sulphur), which will be available for distribution in 2007.

Currently, the ARB is evaluating the overall effectiveness and health implications of control options for heavy-duty diesel and CNG vehicles to determine their advantages and disadvantages. Four types of heavy-duty vehicle/fuel/emission control system were tested.

- Buses using diesel with an oxidation catalyst (baseline)
- Buses using diesel equipped with a continuously regenerating trap for PM (CRT-diesel)
- Buses using CNG without controls (baseline CNG)
- Buses using CNG with an oxidation catalyst (OC-CNG)

Test results show, CRT-diesel buses emitted much less PM and about the same amounts of NO_x, compared to baseline diesel. However, they emitted greater amounts of NO₂ as a fraction of total NO_x. Baseline CNG buses were found to emit a significantly lower amount of NO_x and PM compared to baseline diesel buses, but a higher number of ultrafine PM than CRT-diesel buses. In

addition, baseline CNG buses emitted more aldehyde and mutagenic compounds than either CRT- or baseline diesel buses (Ayala et al. 2002; Holmen and Ayala, 2002). These results prompted the need for additional tests on CNG buses to be equipped with oxidation catalysts.

Preliminary data indicate that the mutagenic activity of exhaust emissions from OC-CNG buses is lower than baseline CNG buses (Ayala et al. 2003). Test findings showed that the transient cycle resulted in higher emissions compared to central business district (CBD) cycle and steady-state (SS) cycle when expressed in units of mass emitted per unit distance travelled by the vehicle. Specifically, the oxidation catalyst fitted CNG bus showed reductions of total PM, total HC, non methane hydrocarbon (NMHC) and CO over both CBD and SS cycles. In contrast, the oxidation catalyst had little effect on NO_x and CH₄. Large fluctuations in NO_x emissions over time have been observed for the CNG baseline transit bus. This may be due to vehicle and fuel variability. CH₄ was found to dominate total HC emissions for both the CNG buses – with and without oxidation catalyst.

Thus, CNG buses with OCs and diesel buses with PM traps or NO_x catalysts appear to be effective future options for reducing emissions relative to baseline diesel buses. A major caveat is that these diesel vehicles will require ultra low sulphur fuel. The results of ARB studies conducted to date underscore the need for regulatory agencies to closely monitor the progress of control technology development in efforts to achieve effective reductions in pollutant emissions and associated public health impacts.

Ultrafine PM emissions

Current PM air quality criteria are mass-based and motivate reducing large diameter PM, but little is known about the ultrafine (diameter <100 nm) and nanoparticle (<50 nm) emissions from alternative engine technologies. Very few studies have examined nanoparticle formation processes for vehicles operating on ultralow sulphur diesel and compressed natural gas. Recently a study was designed to measure the number size distribution of ultrafine and nanoparticles in the exhaust of two in-use 'green' technology heavy-duty vehicles (Holmen and Ayala 2002). The two technologies considered are: (1) a spark-ignition CNG certified for operation without an oxidation catalyst and (2) an conventional diesel bus operating on ultralow sulphur diesel (11 ppm S content) with a passive DPF known as a continuously regeneration trap (CRT) manufactured by Johnson-Matthey. Particle size distributions were analyzed between 6 and 237 nm using 2-minute SMPS (Submicron Particle Size Distribution) scans during

an idling and 55 mile per hour steady state cruise operation. Average particle size distributions collected during idle operation of the baseline bus operating on ultralow sulphur diesel showed evidence for nanoparticle growth under CVS (constant volume sampler) dilution conditions relative to the minidiluter. The CRT effectively reduced both accumulation and nuclei mode concentrations by factors of 10-100 except under CVS dilution conditions. Here nuclei mode concentrations were measured during a 55 mph steady-state cruise that exceeded baseline diesel concentrations. The CVS data suggest some variability in trap performance. The CNG bus had accumulation mode concentrations 10-100 times lower than the diesel baseline but often displayed large nuclei modes, especially under CVS dilution conditions. This may partly be explained by the lack of an oxidation catalyst on the CNG, but differences between the minidiluter and CVS size distributions suggest that dilution ratio, temperature-related wall interactions, and differences in tunnel background between the diluters contributed to creating nanoparticle concentrations that sometimes exceeded diesel baseline concentrations when driving under load. The results do not support use of CVS dilution methodology for ultrafine particle sampling, and despite attention to collection of tunnel blanks in this study, results indicate that a protocol needs to be determined and prescribed for taking into account tunnel blank 'emissions' to obtain meaningful comparisons between different technologies. Of critical importance is determining how temperature differences between tunnel blank and test cycle sampling compare in terms of background particle numbers. Total particle number concentrations for the minidiluter sampling point were not significantly different for the two alternative technologies when considering all the steady-cycle data collected. Concentrations ranged from 0.8 to 3×10^6 particles/cc for the baseline bus operating on ultralow sulphur fuel, from 0.5 to 9×10^4 particles/cc for the diesel bus equipped with the CRT filter, and from 1 to 8×10^4 particles/cc for the CNG bus.

India

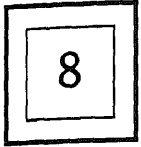
Tighter emission standards have required more specific attention to the treatment of vehicle exhaust emissions. Commonly used technologies to control exhaust emissions include recirculation of exhaust gases, electronic control of engine performance, exhaust after-treatment or emission control devices (like oxidation catalysts, particulate filters, continuously regenerating particulate traps etc.), and advanced combustion techniques. The majority of car manufacturers in India have foreign collaborations for new technologies. This is, however, not true for heavy vehicles, buses trucks, two- and three-wheeled

vehicles. The market share of two- and three-wheelers using two-stroke engines is very high. Apart from the new vehicles, retrofitting of emission control devices can help in reducing emissions from in-use vehicles as well. Not much work has been done in India in this area, which needs to be taken up with the help of R&D institutions and testing agencies.

Conclusions

- 1 Current PM air quality criteria are mass-based and motivate reducing large diameter PM, but little is known about the ultrafine (diameter <100 nm) and nanoparticle (<50 nm) emissions from alternative engine technologies. Very few studies have examined nanoparticle formation processes for vehicles operating on ultralow sulphur diesel and CNG. Test protocols need to be determined and prescribed for evaluating ultrafine and nanoparticle emissions.
- 2 The challenge before the automobile industry would be to work together with the automotive emissions control industry in designing advanced catalysts and trap systems together with optimized engine management and emissions control to bring down auto emissions from new vehicles significantly to meet progressively stringent emission standards and future norms.
- 3 Retrofitting of catalyst systems and particulate traps is increasing in a number of developed countries in response to fiscal incentives introduced by governments in a number of countries aimed at meeting the requirements of cleaning the air quality in cities.
- 4 Sulphur levels in fuels would be very important in the process of selection of technology for post combustion emission control, particularly with the sulphur tolerance of these technologies a major constraint in their development.
- 5 The long-term strategy will be largely based on Euro IV quality fuel and technologies for reduction of PM to 'near' zero levels from current levels.
- 6 Reaching emissions regulations equivalent of US 2007 regulations would require the combined use of DPF and SCR urea based technology whose commercialization would be critical.

- 7 Unregulated emissions and their reduction from spark ignition engines is an area getting increased attention due to the related health effects and this should be a major area of focus for future developments.
- 8 Choice of noble metal for a particular application would be important both in terms of cost and also reduction efficiency of the important emissions from spark ignition engines.



Alternate power packs

Introduction

Sustainable development requires that alternate power packs using electricity and hydrogen as energy carriers are also considered as an option for automotive traction. These alternate power pack based vehicles are expected to evolve in parallel and to yield a sustainable mix with conventional transportation. The mixes in the current and near term will probably be driven by niche markets and in the medium and longer term distinct regional differences will also play a role. In India the switch to alternate power packs will reduce vehicular emission and dependence on oil and, in the longer term, initiate a shift away from hydrocarbon fuels.

High-energy batteries, hybrid power units, and fuel cells are the onboard alternate power packs that are being used for the electric drive train based traction. The penetration level of these alternate vehicles will have to build upon the technological and policy developments pertaining to infrastructure, economics, and safety codes. The Indian Government is aiding the mainstreaming of these alternate power pack vehicles through efforts such as R&D and policy support, fiscal incentives, and regulatory measures. The development and commercialization of alternate power pack vehicles has to be supported because of their environmental advantage. The Mashelkar Committee in its report on Auto Fuel Policy (2002) has also recommended that development activities for alternate power pack based vehicles be accelerated. The Committee also recommended drafting a comprehensive programme for R&D and policy support and other measures for promoting zero emission vehicles(ZEV).

Electric vehicles

An electric vehicle or EV uses electricity stored in an onboard rechargeable battery to power an electric drive train for vehicle traction. Refuelling an EV consists of plugging in the vehicle's charge plug into an outlet that is specifically designed for charging an EV. Recharging time varies, depending on the battery type, capacity and the voltage/current output of the charger. Most EV's can be

recharged in about 6 hours. For the reason an EV uses the energy stored in a rechargeable battery, they are also referred to as battery electric vehicle or BEVs.

Storage batteries for electric vehicles

The storage battery for EV should have a high specific energy density for long driving range, high peak power for good acceleration and climbing, fast recharge for rapid refuelling and high-energy efficiency for economic use of electricity. The cycle life of battery should be 1000 times of discharge/recharge before its capacity goes below 80% of rated capacity.

The ideal battery for an EV is expected to give a maximum driving range of 130 km per charge and a cycle life of 1000 times, this implies that an EV has to login 130,000 km (~ 5 years for private vehicles) before it needs a battery replacement. The battery types available for use in an EV are compared in performance in Table 8.1. The lead-acid batteries are more widely used for EVs because of their low cost and availability, the specific energy for these batteries is in the range 30 Wh/kg to 40 Wh/kg which translates into a driving range of 70–120 km per charge depending on the vehicle type and driving conditions(Barjatia 2001).

Table 8.1 Performance comparison between different batteries

Type	Specific energy (Wh/ kg)	Energy density (Wh/ litre)	Specific Power (W/ kg)	Power density (W/litre)	Self discharge (% month)	Cycle life
Lead-acid	35	70	~200	~400	4-8	250-500
Lithium-ion	115	260	20-250	400-500	5-10	500-1000
Lithium-polymer	100-200	150-350	>200	>350	~ 1	200-1000
Nickel-cadmium	40-60	60-100	140-220	220-350	10-20	300-700
Nickel-metal hydride	60	220	130	475	30	300-500

Source : <http://www.solardome.com/solardome51.html>, as on 12 August 2002

Nickel metal hydride (Ni-MH) batteries offer scope as candidates for mid-term EV application. Ni-MH batteries have a higher specific energy (> 60 Wh/kg) to give a drive range of 120 – 200 km/charge. They however have to overcome the limitations of charge retention especially at elevated temperatures, costs and fast recharging capabilities. Lithium-polymer and Lithium-ion batteries are yet to find wide scale usage for EVs because of higher costs and the difficulties in scaling up the miniature Li technology to sizes and configuration

required for EVs. Nickel-cadmium batteries overcome all these drawbacks, but have exceptionally high costs (Moseley 2001).

Advantages and disadvantages of electric vehicles

An electric vehicle produces zero emissions at the site where it is used and is much more energy efficient than ICE vehicle as energy losses through the transmission and idling simply do not exist. The other advantages include increased reliability, better operating performance, cleanliness, and absence of a fire hazard. There are however associated issues such as high capital vehicle cost attributing to expensive batteries and electric drive train, limited vehicle range and longer recharge timings (6–8 hours) as well as increased vehicle mass to accommodate a battery of appropriate capacity onboard the vehicle. In addition, the electricity consumption for recharging leads to indirect emissions from the utility power plant. The infrastructure for battery charging has also to be created.

International developments

Automobile companies such as Toyota, GM, Honda, and Ford have introduced EVs in the developed countries including US, Japan, and Australia. Table 8.2 compares the EVs available in the international market. To enhance the marketability in the near term while the costs are high, monetary and non-monetary support has been and is being provided in the form of incentives. These incentives are available through the governments in several countries.

Table 8.2 Electric vehicles specification and sales in USA between 1996 and 2002

Manufacturer	Vehicle description	Battery type	Charge time	Expected range (km)	Top speed (km/hr)	Vehicle sales/leasing
General Motors	EV1 Car	Lead acid	6 hr	80-160	130	1110
	S-10 EV	Nickel metal hydride	8 hr	120-200	--	500
Toyota Motors	RAV 4	Nickel metal hydride	6.5 hr	130-160	125	1167
Ford	Ranger EV	Lead acid	6 hr	115	120	1312
	Baker USPS	--	--	--	--	500
Honda	EV Plus	Nickel metal hydride	6-7 hr	144-160	137	300
Chrysler	EPIC	Nickel metal hydride	8-9 hr	112-160	128	207
Nissan	Altra	Lithium ion		128	120	130
Total vehicles sold						5226

Source http://www.evaa.org/evaa/pages/ele_ev_market.htm, as on 1 August 2002

In the United States of America, a federal tax credit of upto 4000 dollars is available for 10% of the purchase price of an EV. In addition there is a utility incentive available in select states to provide a discounted price for the electricity used to recharge an EV. The EVs are also being offered on lease/loan and incentives are being offered to public fleet operators for installing EV charging facilities. Similar incentives are offered in European countries including Italy, Belgium, France, and Switzerland. Non-monetary incentives such as free access to limited traffic zones and relaxation on parking and residential rules for owners of EVs are also being offered.

Electric vehicles—Indian perspective

EVs were launched in India about a decade back and since then manufacturers have introduced buses, cars and three-wheelers powered by onboard batteries.

BHEL has developed and commercialized a 16-seated electric bus, the ElectraVan. The ElectraVan uses a 15 kW electric motor powered by lead-acid batteries. More than 250 ElectraVans have been supplied to customers in the country including IIT Chennai, CVRD Chennai, Anna Zoological Park Chennai, Agra Development Authority, Energy Development Agency of Bihar, Madhya Pradesh, Andaman Nicobar Islands, & Goa, as well to the Agency for Non-conventional Energy Technology, Kerala. More recently ElectraVan was used as shuttle service for ferrying delegates at the COP-8 2002, held in New Delhi. This event was part of EV promotional programme being implemented by the MNES.

The passenger electric car was introduced by the Bangalore-based Reva Electric Car Company (RECC) in June 2001. The electric car uses a 13 kW DC motor powered by lead-acid batteries to give a driving range of 80 km per single charge. The batteries have a life of 40,000 km or 3–4 years. The car is priced between 2.75 and 3.24 lakhs, which is one third that of similar electric cars sold in USA and Europe. Since its introduction, about 300 vehicles have been sold with in India. The company has also exported the Reva electric cars to countries such as Malta, Nepal, Hong Kong, Switzerland, and China.

Mahindra Eco Mobile Limited, a subsidiary of Mahindra and Mahindra have introduced their electric three wheeler, 'Bijlee'. This 10-seater EV powered by a lead-acid battery has a driving range of 90 km per charge. 'Bijlee' three wheelers have been introduced as shared taxis on fixed routes in many cities of India including Delhi, Agra, Mumbai, Pondicherry. The company is also planning to export its EVs to south Asian countries such as Bangladesh, Sri Lanka, Indonesia, and Malaysia.

Scooters India Limited's electric vehicle is the 'Vikram' a three-wheeler EV with a 5.5 kW electric motor powered by a lead-acid battery. Vikram has a range of 100 km per charge and more than 300 units have been introduced in Agra, Delhi, Jaipur, Lucknow, and Kolkata.

Bajaj Auto Limited in association with New Generation Motors of USA have developed an electric three wheeler. The EV christened 'Ecorick' has been undergoing demonstration in Agra since 2001. The initiative is being supported by USAID under the India Zero Emission Transportation Program (IZET). 'Ecoricks' are used by Mughal Sheraton Hotel in Agra to transport guests to local tourist attractions.

The Ministry of Non-conventional Energy Sources has also supported a demonstration programme for 20 battery operated cycle rickshaws (ElecSha) at the Nimbkar Agricultural Research Institute, Phaltan, in Maharashtra. Based on the experience of the demonstration, commercial models of this ElecSha will be introduced in other places to provide a pollution-free mode of transport. The specifications of EV available for sale in India are compared in Table 8.3.

Table 8.3 Electric vehicles of India

Manufacturer	Vehicle description.	Battery capacity	Pay load	Expected range (km)
Eddy Current Cont. (I) Ltd., Coimbatore	Love Bird Car	36V, 150 Ah	Couple+Child	44
Maini Group, Bangalore	Reva Car	48 V, 200 Ah	2 Adults + 2Children	80
Mahindra & Mahindra, Mumbai	3 wheeler Bijlee	72V, 200 Ah	10 seater	90
Scooters India Limited, Lucknow	3 wheeler Vikram	72V, 200 Ah	8 seater	80-100
Bharat Heavy Electrical Limited	Electravan - bus	96V, 300 Ah	16 seater	70

Source : Barjatia 2001

Development and commercialization of EVs in India

Technological issues

Manufacturers of EVs in India are using lead-acid batteries as the onboard power source to keep the vehicle cost low. The Exide Industries Limited, Kolkata, are manufacturing and supplying batteries to all the EV manufactures in India, though new players are also entering into this market. Lead-acid batteries provide a limited driving range and also add to the weight of the vehicle. Vehicle Manufacturers such as Toyota, Honda and Chrysler have also used nickel metal hydride batteries to improve the EV's performance.

The battery charging time of Indian EVs ranges from 6 to 10 hours and electricity consumption is from 9–24 kWh for a 100% recharge. The volume and weight of the onboard charging unit has also to be reduced to achieve better performance.

The Mashelkar Committee (2000) set up by MNES on 'High energy density battery for electric vehicles' has recommended that development activities be initiated with a focus on advanced lead-acid batteries in the short term, nickel-metal hydride batteries in the medium term, and lithium batteries in the long term. This pathway will be an attempt to address the EV limitations related to battery technology as Ni-MH and lithium batteries provides better driving performance.

The Committee also recommended development of efficient and reliable electronic drives and development and use of innovative, quick charging methods and devices for charging batteries. Based on these recommendations the government has initiated R & D support for these critical areas. The development and use of lighter materials for weight reduction of EV's is also being researched.

Infrastructure

The battery-charging infrastructure for electric vehicle is a key issue. Vehicles like the Reva come with an onboard charger and hence owners with a garage facility can use the electrical point in the garage for recharging the EV batteries but for others such facilities would have to be created. For vehicles such as ElectraVan and electric three-wheelers, chargers are not installed onboard to reduce the cost and weight of the vehicle. Facilities for charging the battery of such vehicles has to be provided and should be centralized to keep the operation of such EVs viable. The charging facility comprises electrical connections for use with an off-board charger, where vehicles can come and park to charge EV batteries. The charging time is as long as 6–10 hours so fewer vehicles can be charged. It is advisable to construct fewer but centralised charging stations. This is the reason that ElectraVan and three wheelers are being run on fixed routes.

The manufacturers of EVs such as Scooters India Limited have provided dedicated charging facilities at its dealers sites. The tie-up with public sector oil companies has also been explored, where charging equipment can be installed at their retail outlets. Government agencies are also providing support for installing charging facilities to demonstrate public fleets of electric three - wheelers and buses (Agarwal 2001).

Economics

The higher capital vehicle cost makes it difficult for EVs to compete with well-entrenched diesel and petrol vehicle technology. The auto companies in India are targeting three-wheeler markets for introducing their electric vehicles, since this is the only market where EVs may have prospects of becoming economically viable. Scooters India Limited and Mahendra Eco Mobiles Limited estimated that a battery-operated vehicle with 50% concession on power tariff and custom duty for battery can be economically viable. This incentive may help the EVs to achieve a total cost of Rs 1.35 per km as against Rs. 1.38 per km for a diesel, and Rs. 3.39 per km for a petrol-driven vehicle.

In order to make EV's economically viable for public transport, the Ministry of Non-conventional Energy Source has initiated a subsidy programme for promoting battery-operated vehicles in niche markets. A central subsidy to the extent of 50% of the cost of the vehicle exclusive of the excise duty, sales tax, and other levies has been provided for the purchase of 10-seater and bigger passenger vehicles operated by battery. In addition, some incentives are also being provided at state level; the Delhi Government has announced a 0% sales tax for zero emission vehicles.

Prospects

Technological improvements in the Indian electrical vehicle are expected to facilitate their acceptance and market penetration. The mechanism for development and commercialization of EVs in India is being built by a consortium approach with the involvement of R & D organizations, battery, and EV manufacturers, ARAI, VRDE, and government ministries. The present know-how will provide a sounding board for reaching out to advanced electric vehicle technology.

Target users for EVs will be mini transport vehicles, urban service industries, the service sectors and governments at the central and state levels. The Regulation such as those in Agra which allow the use of only zero emission vehicles(ZEVs) in a five km radius around the Taj Mahal will facilitate the penetration of EVs in such niche markets. More recently, the Ministry of Environments and Forests also initiated a drive to introduce EVs in national zoological parks in the country to improve the environment. It is felt that regulations rather than incentives will be the drivers of penetration of EVs in niche markets in India.

Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) represent a cross between a conventional automobile and an electric vehicle. They combine an electric drive train, including a battery or other energy storage device, with a quickly refuelable power source such as a petrol or diesel engine, fuel cell, or gas turbine. A controller onboard an HEV directs the allocation of power between the battery, the engine/ generator set and the electric drive train. The HEVs were developed to overcome the limitations of a purely electric vehicle while improving the fuel economy of a conventional vehicle.

Technologies

Series Hybrid Configuration

In this type of configuration, a small fuel-burning engine directly drives an alternator to generate electricity. The electricity is then stored in the batteries or sent to the electric motor, which powers the wheels. Series hybrids use large battery packs to improve efficiency advantage from a small engine. Since batteries and motors cost more than engine for the same amount of power, series hybrids are more expensive than parallel hybrids described below.

The series hybrids have an advantage under slower operating conditions characterized by stop-and-go-driving. During high speed and highway driving, the inefficiency of always converting the mechanical power from the engine into electricity, storing some of it, and then converting it back to mechanical power takes its toll. For this reason series hybrids currently under development are for buses and heavy-duty vehicles.

Parallel Hybrid Configuration

A parallel HEV is configured with two power paths, so that either the engine, or the electric propulsion system, or both, can be used to produce the motive power to turn the wheels. Parallel drive trains require an engine that is smaller than a conventional vehicle, but is typically large and thus more expensive than series hybrids. The higher engine cost of parallel HEVs is however, offset by the lower cost of the small motor and battery packs compared to the series hybrids.

In a parallel HEV the engine is directly connected to the wheels, thus parallel HEVs don't suffer the efficiency penalty experienced by series HEVs on the highway. In the city, the parallel arrangement will reduce, though not eliminate, some of the efficiency benefits of a parallel drivetrain. The parallel HEVs provide advantages in both city and highway driving conditions.

Dual mode hybrids

The dual hybrid combines the features of parallel and series HEVs. While driving at the highest speed, the vehicle operates in the parallel mode with the engine driving the wheels directly to minimize the inefficient energy conversion step of the series hybrid. However the engine can be effectively disconnected from the transmission during low speed driving and operated in the same way as a series HEV. The performance of the dual mode is better than either the parallel or series, however it inherits complexity and high cost from each of these HEV types.

Features of hybrid electric vehicles

HEVs operate on the electric-only mode during vehicle start-up and stopping/idling, thus eliminating the emissions, which are highest during these modes. Regenerative braking recovers mechanical energy of the vehicle during braking to charge the batteries. The incorporation of an onboard battery traction system helps in downsizing the onboard gas engine, though integration of the two power units requires installation of complex controllers.

The fuel economy benefits of HEVs are over and above those that can be achieved with a conventional engine and are better for hybrid vehicles that are closer to a full function battery electric vehicle. HEVs do not have substantial advantages over conventional vehicles in decreasing tail pipe emissions. The primary emissions advantage of most hybrids is that they can use smaller, lighter engines, which heat up quickly. Faster heating reduces start-up emissions, which are the primary challenge in achieving lower exhaust emission levels.

Development and commercialization of HEVs

International scenario

Hybrid electric cars are available in the market in many countries including USA, Japan, and European countries. The Toyota has introduced an HE car 'Prius', whereas Honda has two different versions, 'Insight', and 'Civic'. These HEVs cost 6000 dollars more than conventional vehicles and the fuel economy is about twice that of conventional cars. The emission levels of these cars meet the second strictest regulation in existence: the ULEV or the ultra-low emission vehicle.

HEV technology is also used for transit buses with standard diesel engines as the onboard power unit. Several manufacturers such as Volvo Cumulo, Iveco,

DAB, Neoplan, and Mercedes Benz have all built prototypes and some have reached volume production.

To promote HEVs several incentives are being provided. In the US, a 2000 dollar federal tax deduction is being provided. In Japan, HEV owners receive an Automobile Acquisition Tax break of 2.2% and this is further encouraged by removing 3000 dollars from the purchase price of the vehicle before calculation of the acquisition tax. The incentives are providing strong structural reasons for automakers to go ahead with HEVs and the sales volume of HEVs sold in last 5 years (Table 8.4) again reflects this. The leading manufacturers of HEVs are the Toyota and Honda, though Ford Motor Company will also be entering the HEV market and plans to start commercial production of its HEVs by 2007.

Table 8.4 Hybrid electric cars manufactured and sold between 1997-2002

Manufacturer	Model	Battery type	Hybrid type	Mileage (km/litre)	Price (US\$)	Vehicle sales/leasing (Dec1997-Sep 2002)
Toyota Motors	Prus	Nickel-metal hydnde	Dual mode	20-22	20,480	100,208
Honda	Insight	Nickel-metal	Parallel	26-29	19,080	12,000
	Civic	hydnde		19-21	19,550	~ *

Source : http://www.toyota.co.jp/IRweb/special_rep/toyotasells/03.htm, as on September 25, 2002

Indian initiative on HEVs

In India a hybrid electric bus has been developed by Ashok Leyland in collaboration with the Department of Scientific and Industrial Research, Electronic Research and Development Centre (Trivandrum) and Ministry of Information Technology. The bus combines a diesel engine with on-board batteries to drive an AC induction motor. The prototype is undergoing test for performance evaluation under the Indian driving cycle and the plans are to introduce this bus as an alternative to CNG bus in cities where the natural gas infrastructure is not available. The current costs of the bus are high, attributing to the expensive onboard battery and electronic systems.

The TVS Motor Company has introduced parallel hybrid electric three-wheelers. The vehicle uses valve-regulated lead-acid batteries with a 4- stroke ICE to achieve a top speed of 65 km/hr. The hybrid system is configured for operation in crowded Asian cities such as Delhi and Bangkok. The 3-wheeler

* As per an estimate, the Civic has been meeting Honda's target of 2000 cars/month since its introduction in April 2002.

like the HE bus is costlier than its conventional counterparts and is undergoing tests.

The hybrid electrics in India can provide lower emission vehicles for urban transport. The higher cost of the Indian HEVs however has to be offset by incentives such as tax subsidies. The Delhi Government recently announced a scheme of 0% sales tax on ZEVs is also applicable for HEVs.

Fuel Cell Vehicles

A fuel cell vehicle or FCV uses an onboard fuel cell as power source in combination with a storage battery to provide traction to an electric drive train vehicle. The FCV's offer low or zero emissions, while maintaining performance standards that are at least equal to those of ICE vehicles.

The fuel cell generates electricity from hydrogen fuel via a combustion-free electrochemical conversion process. Because there is no combustion in the fuel cell itself, the system on its own is emission free and since the conversion bypasses the conventional Carnot cycle, the efficiencies are higher than the internal combustion engine.

Fuel cells for automotive traction

The polymer electrolyte membrane fuel cell technology (PEMFC) has emerged as the fuel cell type to replace ICE for propulsion power. The decision is based on considerations including the ability to fit the size and weight of the power plant under the hood of the car, the ability to start up quickly, the ability to meet the changing power demands (dynamic response) typical in a driving cycle and cost. The solid oxide fuel cell (SOFC) is being also looked into as an auxiliary power source for cars based on the 42 volts battery system.

There are fuel cell technologies, such as the direct methanol fuel cell (DMFC) and direct ethanol fuel cell (DEFC), which can directly use methanol and ethanol vapours for generating electricity for FCVs. Both these technologies are still being developed and considerable improvements will be required before DMFC/DEFC will commercially find a place as traction units for fuel cell vehicles.

The current capital cost of these fuel cell systems is about 3000 to 5000 dollar per kilowatt. As per the industry estimate, for fuel cell vehicles to become competitive with commercial vehicle technologies, the fuel cell costs will have to drop down to 50–60 dollars/kW.

Fuels for fuel cell vehicle

Pure hydrogen is the fuel of choice for FCV's to achieve true zero emission criteria. Hydrogen fuelled FCVs will emit only water vapour in its exhaust. However for this to happen on a commercial scale, safe and efficient technologies for storing hydrogen onboard the vehicle will have to be developed, resources be identified and infrastructure for hydrogen supply be built-up.

Hydrocarbon fuels such as petrol, methanol, ethanol, natural gas, and diesel when used in FCV's would need an onboard fuel processor to extract hydrogen for the fuel cell unit. Fuel processing technologies such as partial oxidation, catalytic partial oxidation and auto-thermal reforming are being fine-tuned to use hydrocarbon fuels onboard an FCV. The technological problems pertaining to matching the response of onboard fuel processors with vehicle driving energy demands still remain a challenging area. In addition, this results in carbon monoxide and nitrous oxide emissions that, to some degree, compromise the environmental integrity of the system. Table 8.5 compares the on-board hydrogen fuel storage options for FCVs with their petrol-fuelled counterparts.

Table 8.5 Comparison of on-board hydrogen storage options

	Petrol	Compressed hydrogen	Liquefied hydrogen	Metal hydride (Ovonics Mg alloy)
Btu	1,334,540	629,500	629,500	629,500
Fuel weight (kg)	29.5	4.7	4.7	4.7
Tank Weight (kg)	13.4	63.3-86	18.6	120
Total weight of fuel system (kg)	43.2	67.9-90.5	23.3	124.7
Volume (litres)	40.1	408.8-227.2	177.9	120
Range (km)	600	600	600	570

Source : Amos 1998

Development and commercialization of FCVs

International perspective

Developed countries with major automotive manufacturing capacities have adopted strategies and incentives to accelerate the adoption and deployment of fuel cell technology into vehicle fleets. The industry perceives a public policy need to accelerate the deployment of this technology and is thus investing in research and demonstration, adopting incentives and conducting educational activities.

The public policy drivers for FCV's in the developed world mainly revolve around emission reduction and efficiency improvement. While European

countries stress on deployment of fuel cell technology for the benefits of CO₂ reduction to global climate change, the United States stresses energy efficiency and petroleum savings. Japan and Canada look at it as an area in which they can provide world-leading technology. China sees it as a visible way to demonstrate its commitment to a clean environment at the Beijing Olympics in 2008.

Investment, alliances, and partnerships

The global investment in fuel cell technology in the financial year 2001 exceeded 400 million dollars (Yoshida 2003). The automotive R & D alliances in the FCV area are growing and this is also helping fuel cell manufacturers to combine their technical know-how with the resources of automotive manufacturers.

Other stakeholders such as fuel suppliers are also being involved to evolve a long-term strategy for deployment of fuel cell vehicles. For example, Ford has an alliance with Ballard Power System[#] (Canada) and DaimlerChrysler (Germany) for developing fuel cell technology. Ford has also an alliance with ExxonMobil to explore the onboard generation of hydrogen from fossil fuels such as methanol and petrol. The demonstration of FCV's with onboard hydrogen is being carried out through alliances such as the California Fuel Cell Partnership. Other major alliances are:

- Ballard/DaimlerChrysler/Ford/Mazda/Volvo
- DaimlerChrysler/Mitsubishi
- General Motors/Toyota
- General Motors/Opel/Suzuki
- Nissan/PSA Peugeot Citroen/Renault
- BMW/Renault/Delphi
- United Technologies/Hyundai

The US Government in recent times has been supporting the development of FCV's and a hydrogen economy by providing R & D subsidies to the tune of 2.7 billion dollars through its FreedomCAR (January 2002) and Hydrogen Fuel Initiative (January 2003). The programme aim at partnerships between the government and industry to accelerate the development of FCV's, improve the performance of the hydrogen fuel cell technology and to make it commercially viable and to develop a renewable means of generating hydrogen.

In Japan the government in response to FreedomCAR has plans to increase R & D support for fuel cell technology with programmes built on synergies

[#] Ballard Power Systems is the leading supplier of PEMFC engine for transportation and has introduced its Mark 902 fuel cell platform.

across academia, government and industry. The Japanese Government envisages the deployment of 5 million FCV's and 10 million kW stationary fuel cell generation capacities by 2020.

FCV demonstrations

The ten leading auto companies of world have ongoing programmes to introduce FCVs, including buses and cars. The details as shown in Table 8.6 and Table 8.7 indicate that FCV manufacturers (with the exception of Toyota) are evaluating compressed hydrogen as an onboard fuel for FCVs. The cities of Vancouver and Chicago each operated three fuel-cell buses fuelled by hydrogen on urban routes in regular service, as a part of two year demonstration programme.

DaimlerChrysler has demonstrated its hydrogen powered FC buses in municipal transit systems in Europe under the ECTOS, CUTE, and STEP programmes. These FC buses use a 205 kW PEM fuel cell engine supplied by Ballard Power System of Canada.

DaimlerChrysler, Toyota, and Honda have demonstrated fuel cell cars. The latest versions of FC cars were introduced by Toyota and Honda late in 2002 and under a lease programme there have been provided to the Japanese Government and universities in USA. The Japanese Government has also agreed to include more FC cars in its vehicle fleet. The details of FCVs introduced by auto manufacturers are provided in Table 8.6 and Table 8.7.

Issues and prospects

The onboard storage of hydrogen is emerging as the choice for FCVs. The onboard hydrogen storage simplifies vehicle design but has to address the issue of safe onboard storage, and driving range. Storage options such as compressed gas,

Table 8.6 Fuel cell based heavy duty vehicles developed by automotive companies

Manufacturer	Vehicle detail	Year	Fuel cell size/type	Fuel type	Range (km)	Top Speed (km/hr)
EvoBus	Citaro Bus	2003	205 kW/PEMFC	CG H ₂ * @ 5,000 psi	200	80
Irisbus	Fuel cell bus	2001	60 kW/PEMFC	CG H ₂	----	----
Hino Motors Ltd	Fuel cell bus	2002	180 kW/PEMFC	CG H ₂ @ 5,000 psi	300	80
Neoplan	33 seat bus	2000	80 kW/PEMFC	CG H ₂	250	80

*CG H₂ = Compressed gaseous hydrogen

Source . <http://www.fuelcells.org/charts.htm>, as on February 12, 2003

Table 8.7 Fuel cell based light duty vehicles developed by automotive companies

Manufacturer	Vehicle detail	Year	PEMFC fuel cell engine size (kW)	Fuel type	Range (km)	Top Speed (km/hr)
General Motors	HydroGen 3	2002	94	CG H ₂ @ 10,000 psi	270	160
Ford	Advanced Focus	2002	85	CG H ₂ @ 5,000 psi	290	----
DaimlerChrysler	NECAR 5.2	2001	85	Methanol	482	150
	Sprinter Van	2001	85	CG H ₂ @ 5,000 psi	150	120
	Natrum Mini Van	2001	54	Sodium Borohydride	483	129
Honda	FCX - V4	2001	85	CG H ₂ @ 5,000 psi	300	140
	FCX	2001	85	CG H ₂ @ 5,000 psi	355	150
Toyota	FCHV - 5	2001	90	Low S clean petrol	----	----
	FCHV - SUV	2002	90	CG H ₂ @ 5,000 psi	290	155
Volkswagen	HyPower	2002	40	CG H ₂	150	----
Nissan	X - TRAIL SUV	2002	75	CG H ₂ @ 5,000 psi	----	125
Renault	EU - FEVER	1997	30	LH ₂	400	120
BMW	Series 7 (Sedan)	2000	ICE + 5 kW	Petrol/ LH ₂	300	140
			PEMFC			
Daihatsu	MOVE FCV - K II (mini vehicle)	2001	30	CG H ₂ @ 3,600 psi	120	105

Source : <http://www.fuelcells.org/charts.htm>, as on February 12, 2003

liquefied gas and in metal-hydrides are being tried. In recent times carbon nano-fibres are also being explored as they have hydrogen storage densities of 75 weight percent near room temperature.

The sources of hydrogen in the near term are likely to be from reformation of fossil fuels but in the medium and longer term, renewable sources of hydrogen will have to be established such as those from electrolysis using electricity produced from renewable technologies. Countries like Iceland and Canada with sizeable hydropower generation potential are vigorously pursuing hydrogen based fuel distribution systems and fuel cell vehicle based transportation. This is because hydro-electricity could provide clean and cheap renewable electricity for hydrogen production from the electrolysis of water.

In addition to hydrogen generation the hydrogen transport, distribution, and refuelling infrastructure has to be put into place for catering to large commercial fleets of FCVs. The transport of hydrogen in pressurized containers and via pipelines (similar to natural gas) is already in practice, though on a limited scale and in developed countries such as USA and those in Europe. Hydrogen

refuelling stations are being demonstrated in developed countries such as Japan, USA and Germany, and it is expected that a few more of such stations will come up in the next 3–4 years. The safety codes and regulations for hydrogen transport, distribution and refuelling have to be put in place before commercial operation of fuel cell vehicles is initiated (Lakeman, 2001).

The commercial viability of fuel cell technology will be proven in the mass transit market before in-roads are made into the passenger vehicle market. The fleets for mass transit will also be taking advantage of a centralized refuelling facility thereby reducing investment in decentralized infrastructure. Although fuel cell buses are heavier than a standard bus, conventional performance standards such as acceleration and braking standards are maintained in the FC bus.

Unlike fleets for mass transit, the penetration of FC technology in passenger cars will require development of extensive hydrogen fuel distribution and refuelling infrastructure. In addition the means of generating hydrogen for meeting the demands of millions of passenger car will have to be evaluated with a long-term perspective. The timeline for developing transition to hydrogen economy is seen only after 2015 and beyond.

Fuel cell vehicles—the timeline

DaimlerChrysler, General Motors, Ford, Toyota, Honda and Nissan predict that full commercialization for the public will begin around 2010, starting with fleet vehicle demonstration programmes in 2002–2004 followed by fleet commercialization. The fuel cell vehicle in general, is expected to conform to the following timeline as follows:

- 2002–2004: Prototypes and first production FCVs to undergo public road tests in USA, Europe, and Japan.
- 2006–2007: Next generation fuel cell systems incorporated in FCVs and expansion of demonstration fleets in USA, Europe, and Japan
- Starting 2010: Marketing of commercially viable FCVs at affordable prices – this will be the first step towards the initial penetration of FCVs in the transportation sector.

Indian perspective

Research, development and demonstration

Fuel cell technology research in India is being supported by the MNES and recently by the CSIR. Fuel cell stacks of various sizes and types have been developed by research institutes and organizations such as BHEL at Hyderabad

(phosphoric acid fuel cell stack, 50 kW), SPIC Science Foundation at Chennai (PEMFC, > 5 kW), TERI at Delhi, and the Central Electrochemical Research Institute at Karaikudi (molten carbonate fuel cell stack 100 – 350 W).

The SPIC Science Foundation have integrated their > 5 kW PEM fuel cell stack into an electric vehicle. The electric vehicle is a 12-seater van purchased from M/s Chatlec Vehicles India Ltd, Mumbai. The hydrogen fuel for fuel cell unit is stored onboard the vehicle in pressurized cylinders. The two 5 kW stacks (developed by SPIC Science Foundation) in combination with an onboard battery provide traction to the electric vehicle. The vehicle is undergoing trials at the SPIC Science Foundation Campus at Chennai.

India along with China, Brazil, Argentina and Mexico was chosen by the UNDP – GEF as a site for a fuel cell bus demonstration project. The fuel cell bus demonstration project of India aims at demonstrating custom built fuel cell buses and hydrogen refuelling infrastructure in city of New Delhi to reduce emission from mass transit systems in urban areas. The project is to be co-financed by UNDP – GEF and Indian stakeholders including government and automobile industry. The inclusion of the technology transfer component for fuel cell bus technology from US/ European supplier to Indian automobile manufacturers and co-financing by industry partners will however determine the success of this project.

Prospects for FCVs in India

In India, most vehicles are concentrated in the urban areas, and as the fleet grows, concerns over emissions and energy use are expected to grow as well. The Government is analysing the option of deploying fuel cell buses for mass transit in urban areas as the fuelling infrastructure can be established much more easily than for passenger cars. The large size of the market will also help in creating cost reduction through economies of scale. In addition to this, the power unit for the Indian vehicle is smaller than those in developed countries. This is because buses in developed countries incorporate facilities such as air-conditioning, pneumatic doors as well communication and tracking equipment. For example while a bus in the US requires a 205 kW fuel cell stack, the bus in India will need only about 120 kW, thus providing a 30% reduction in the fuel cell power unit cost.

The critical factor will be to develop an appropriate supply chain and infrastructure for hydrogen fuel for operating commercial fleets of FCVs. Sources of hydrogen in the country exist but techno-economically viable options have to be identified. For example existing technology for producing hydrogen

from naphtha and natural gas in refineries can be effectively used for catering to commercial fleets of fuel cell buses in cities that are located close to the refineries. This will have to evolve from regulations or intervention initiatives of government agencies that promote the use of such advanced technologies.

Conclusions

Electric vehicles

- 1 Electric vehicles have zero emission locally but tend to shift the emissions to the power plant site. The comparative compromise of EVs against a conventional vehicle in terms of limited driving range, longer refuelling (recharging) time, lack of refuelling (recharging) infrastructure and high vehicle capital cost etc. indicates that penetration of EVs in personal vehicle markets will be minimal. The total sale of personal EVs in USA where the government has been quite liberal in providing monetary and non-monetary incentives, is less than 6000 vehicles in last five years.
- 2 In India, the use of EVs will probably be restricted to specific areas where there are serious concerns about the air quality. These areas, for instance could be in crowded routes of metropolitan cities, world heritage sites, such as the Taj in Agra and of course at places like zoo, trade promotion campuses etc. A public fleet of EVs will be more practical since centralized infrastructure for battery recharging can be provided at minimum cost as also the training of the drivers could be addressed in convenient mode.

Hybrid electric vehicles

- 1 HEVs to an extent, address some of the technical difficulties faced by the EV technology and the issues of emission and efficiency from a pure ICE vehicle. The driving comforts and the reliance on the hydrocarbon fuel infrastructure has facilitated moderate acceptance by customers. This is more evident by the fact that since its introduction in 1997, the sale of hybrid vehicles has crossed 0.15 million vehicles worldwide.
- 2 The HEVs will be a bridging technology that, in the near term, will address the challenges of EVs and in the longer term facilitate a transition to fuel cell vehicle based transportation by bring down the costs of electric drive train components and developing experience for integration with fuel cell power units.

Fuel cells vehicles

- 1 Automotive majors such as Toyota, Honda, Nissan, DaimlerChrysler etc. all have ongoing programmes to develop fuel cell vehicles. The timeline estimates indicate that by 2010 FCVs will be available to customers.
- 2 Compressed hydrogen has emerged as the fuel of choice for FCVs to achieve a zero emission vehicle, though other carbon-based fuels are also being tried. It is felt that in the longer term hydrogen will emerge as the fuel of choice for FCVs. The commercialization of FCVs, both for mass transit and personal vehicles will have to concurrently address the issue of large scale generation, production, transport, and storage of hydrogen.
- 3 In case of liquid fuels, though infrastructure for distribution and refuelling is available, the on-board reforming is a complex process and also leads to emissions from reformation.
- 4 The fuel cell systems at present have a high capital cost that has a direct impact on the cost of the vehicles. It has been evaluated by several manufacturers that for the fuel cell vehicle to be competitive with its ICE counterparts, the fuel cell system costs have to drop to 50–60 dollars/kW from the present 3000–5000 dollars/kW.

Annexes

Annex 2.1 Urbanization trends

Table 1 Number of urban agglomerations/towns by size class

Class	1951	1961	1971	1981	1991	2001
Class I (1,00,000 & above)	76	102	148	216	296	393
Class II (50,000-99,999)	91	129	173	270	341	401
Class III (20,000-49,999)	327	437	558	738	927	1151
Class IV (10,000-19,999)	608	719	827	1053	1135	1344
Class V (5,000-9,999)	1124	711	623	739	725	888
Class VI (less than 5,000)	569	172	147	229	185	191
All classes	2795	2270	2476	3245	3609	4368

Source. <http://urbanindia.nic.in/mud-final-site/urbscene/index.htm> as on February 2003, Central Statistical Organisation

Table 2 Urban population by size class India

Class	1951	1961	1971	1981	1991	2001
Class I (1,00,000 & above)	27,506,519	39,882,780	61,225,798	94,503,745	138,801,945	193,497,234
Class II (50,000-99,999)	6,136,734	8,712,782	11,679,940	18,189,728	23,309,167	27,525,925
Class III (20,000-49,999)	9,688,132	13,138,936	17,125,811	22,409,119	28,079,305	34,812,953
Class IV (10,000-19,999)	8,398,871	9,902,236	11,706,334	14,930,267	16,531,064	19,468,783
Class V (5,000-9,999)	7,992,923	5,328,762	4,755,659	5,603,015	5,532,033	8,712,504
Class VI (less than 5,000)	1,906,467	596,504	472,992	783,894	613,823	665,229
All classes	61,629,646	77,562,000	106,966,534	156,419,768	212,867,337	284,682,628

Source. <http://urbanindia.nic.in/mud-final-site/urbscene/index.htm> as on February 2003, Central Statistical Organisation

Annex 2.2 Urbanization, economic and vehicular growth

Table 1 Urbanization levels and share in total Indian vehicular population of states

State	1981		1985		1990		1995		1999		NSDP at 1993-94 prices (in million Rs.)
	Level of urbanization (in %)	Share in total vehicle pop (in %)	Level of urbanization (in %)	Share in total vehicle pop (in %)	Level of urbanization (in %)	Share in total vehicle pop (in %)	Level of urbanization (in %)	Share in total vehicle pop (in %)	Level of urbanization (in %)	Share in total vehicle pop (in %)	
Andhra Pradesh	23.37	4.74	24.81	5.72	26.73	6.66	27.61	7.63	27.39	7.51	710310
Arunachal Pradesh	6.76	0.01	8.83	0.00	12.45	0.03	16.57	0.05	19.60	0.04	91700
Assam	11.31	1.11	11.26	1.38	11.09	1.33	11.77	1.06	12.45	0.94	155800
Bihar	12.47	3.51	12.76	3.81	13.10	4.79	10.43	3.94	10.45	1.80	264610
Gujarat	31.07	7.10	32.40	10.27	34.33	9.60	35.93	10.00	37.03	10.72	624500
Haryana	21.93	2.37	23.09	2.24	24.51	2.49	26.16	3.15	28.09	2.91	270280
Himachal Pradesh	7.61	0.56	8.01	0.39	8.64	0.31	9.22	0.35	9.66	0.31	63000
Jammu & Kashmir	21.06	0.68	22.14	0.61	23.71	0.57	23.64	0.58	24.51	0.45	72700
Karnataka	28.87	7.88	29.75	7.39	30.81	6.70	31.92	6.66	33.29	7.01	583130
Kerala	18.91	3.76	21.70	3.45	26.08	3.03	28.40	3.46	27.26	3.68	327160
Madhya Pradesh	20.34	5.94	21.52	6.13	23.04	6.83	26.15	6.84	26.59	7.14	463280
Maharashtra	35.00	16.11	36.46	15.18	38.52	12.65	40.36	11.94	41.86	12.63	1422170
Manipur	26.69	0.11	27.47	0.16	27.37	0.22	25.64	0.18	24.18	0.16	18300
Mizoram	25.51	0.05	33.36	0.04	45.07	0.05	52.44	0.05	51.66	0.04	NA
Nagaland	15.61	0.11	16.28	0.05	17.07	0.30	17.33	0.30	17.56	0.30	16140
Orissa	11.85	1.22	12.51	1.20	13.28	1.98	13.94	1.95	14.63	2.03	188090
Punjab	27.65	6.25	28.47	6.51	29.46	6.22	30.88	5.67	32.91	4.74	357330
Rajasthan	21.04	3.89	21.82	3.51	22.78	5.06	23.25	5.24	23.37	5.60	474020
Tamil Nadu	32.82	6.21	33.29	6.55	34.07	7.20	36.65	8.20	41.29	9.53	757900
Tripura	11.05	0.16	12.56	0.11	15.11	0.10	17.06	0.10	17.37	0.09	25320
Uttar Pradesh	17.99	8.68	18.81	8.69	19.75	8.88	20.14	8.81	20.59	9.56	910270
West Bengal	26.36	6.89	26.79	4.95	27.43	3.94	27.77	3.67	27.97	3.49	736090
A & N Islands	26.34	0.04	26.25	0.04	26.77	0.04	28.05	0.04	30.96	0.03	NA
Chandigarh	92.82	1.05	91.21	1.21	89.73	1.21	88.56	1.10	89.06	0.80	24400
Dadra & Nagar Haveli	6.63	0.01	7.60	0.00	8.78	0.03	11.98	0.03	18.78	0.03	NA
Daman & Diu	36.21	0.68	40.87	0.66	46.82	0.04	52.52	0.06	43.10	0.07	NA
Delhi	92.04	10.36	90.90	9.17	89.94	8.48	89.85	7.78	91.69	7.07	318750
Pondicherry	52.60	0.49	57.10	0.43	63.46	0.37	67.15	0.35	67.31	0.48	17720

Details of Goa, Jharkand, Chattisgarh, Meghalaya, Sikkim, Uttaranchal and Lakshwadeep not given in the above table due to data gaps

The table gives the level of urbanization for various states defined as the urban population as a percentage of the total population in each state. It also gives the total vehicle population in each state as a percentage of the total vehicle population in the country.

Source. Data on urbanization Census of India, vehicles from MoRT&H and NSDP from CSO

Table 2 Growth of population and motor vehicles member in metropolitan cities

Major cities	Population			Vehicle population		
	1991	2001	Annual growth rate % (1991-2001)	1991	2001*	Annual growth rate % (1991-2001)
Mumbai	12,571,720	16,368,084	2.67	628488	916485	3.84
Kolkata	10,916,272	13,216,546	1.93	475032	714419	4.17
Delhi	8,375,188	12,791,458	4.33	1812967	3517632	6.85
Chennai	5,361,468	6,424,624	1.83	543978	1147722	7.75
Hyderabad	4,280,261	5,533,640	2.60	442689	969266	8.15
Bangalore	4,086,548	5,686,844	3.36	576914	1341512	8.80
Ahmedabad	3,297,655	4,519,278	3.20	374128	788133	7.74
Pune	2,485,014	3,755,525	4.22	280263	572885	7.41
Kanpur	2,111,284	2,690,486	2.45	169066	326309	6.80
Jaipur	1,514,425	2,324,319	4.38	266254	571185	7.93
Lucknow	1,642,134	2,266,933	3.28	215547	428276	7.11
Nagpur	1,661,409	2,122,965	2.48	167208	309467	6.35

*estimated by TERI

Source. Population data from Census of India

Annex 2.3 Regression results

Table 1 Econometric equation for cars and jeeps in selected states

Variable	Andhra Pradesh		Bihar		Delhi		Gujarat		Karnataka		Maharashtra	
	C	PCNDP	C	PCNDP	C	PCNDP	C	PCNDP	C	PCNDP	C	PCNDP
Coefficient	-1.13	0.00049	-1.41	0.0009	-25.19	0.0038	-4.13	0.00094	-1.77	0.00077	0.65	0.00046
Std. error	0.17	0.00004	1.38	0.0004	3.46	0.0002	0.69	0.00007	0.18	0.00002	0.43	0.00004
t-Statistic	-6.56	13.49	-1.02	1.95	-7.28	19.03	-5.97	13.11	-9.79	31.21	1.52	11.25
Prob.	0.00	0.00	0.32	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00
R-square	0.91		0.18		0.95		0.91		0.98		0.88	
N	19		20		20		20		20		20	

PCNDP stands for per capita NDP, C for the constant term, AR for auto regression, N for number of observations considered

Table 2 Econometric equations for cars and jeeps in selected states

Variable	Rajasthan		Tamil Nadu		Uttar Pradesh		West Bengal		Rest of India	
	C	PCNDP	C	PCNDP	AR(1)	AR(2)	C	PCNDP	C	PCNDP
Coefficient	-2.10	0.00067	-1.67	0.00071	0.90	-0.28	0.5594	0.0005	-4.06	0.0008
Std. error	0.33	0.00005	1.04	0.00011	0.25	0.25	0.5642	0.0001	0.88	0.0001
t-Statistic	-6.39	12.91	-1.61	6.29	3.61	-1.12	0.99	5.75	-4.61	7.46
Prob.	0.00	0.00	0.13	0.0000	0.00	0.28	0.33	0.00	0.00	0.00
R-square	0.90		0.96		0.84		0.65		0.76	
N	20		18		20		20		20	

PCNDP stands for per capita NDP, C for the constant term, AR for auto regression, N for number of observations considered

Table 3 Econometric equations for two-wheelers in selected states

Variable	Andhra Pradesh			Bihar			Delhi			Gujarat			Karnataka			Maharashtra		
	C	PCNDP	AR(1)	C	PCNDP	AR(1)	C	PCNDP	AR(1)	C	PCNDP	AR(1)	C	PCNDP	AR(1)	C	PCNDP	AR(1)
Coefficient	-31.67	0.0073	0.42	-11.70	0.006	0.006	-22.34	0.0083	0.0083	-39.62	0.00787	0.00787	-24.36	0.0066	0.0066	-18.39	0.0039	0.0039
Std. error	4.51	0.0006	0.25	14.84	0.005	0.005	13.58	0.0079	0.0079	5.91	0.00061	0.00061	1.93	0.0003	0.0003	2.09	0.0002	0.0002
t-Statistic	-7.03	11.5336	1.67	-0.79	1.31	1.31	-1.64	10.47	10.47	-6.70	12.8710	12.8710	-12.60	24.90	24.90	-8.79	19.57	19.57
Prob.	0.00	0.00	0.11	0.44	0.21	0.21	0.12	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00	0.00
R-square			0.96		0.08	0.08		0.86	0.86		0.90	0.90		0.97	0.97		0.96	0.96
N			19			20			20			20			20			20

PCNDP stands for per capita NDP, C for the constant term, AR for auto regression, N for number of observations considered

Table 4 Econometric equations for two-wheelers in selected states

Variable	Rajasthan			Tamil Nadu			Uttar Pradesh			West Bengal			Rest of India		
	C	PCNDP	AR(1)	C	PCNDP	AR(1)	C	PCNDP	AR(1)	C	PCNDP	AR(1)	C	PCNDP	AR(1)
Coefficient	-22.54	0.00607	0.36	-39.83	0.01	0.36	-36.32	0.0095	0.0095	-10.70	0.00260	0.00260	-38.19	0.006	0.006
Std. error	2.74	0.00043	0.27	3.31	0.00	0.27	3.28	0.0007	0.0007	0.57	0.00009	0.00009	7.91	0.001	0.001
t-Statistic	-8.24	14.13	1.35	-12.04	19.98	1.35	-11.08	14.04	14.04	-18.62	29.53	29.53	-4.83	6.71	6.71
Prob.	0.00	0.00	0.20	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R-square		0.92	0.98			0.98		0.92	0.92		0.98	0.98		0.71	0.71
N		20	19			20			20			20			20

PCNDP stands for per capita NDP, C for the constant term, AR for auto regression, N for number of observations considered

Table 5 Econometric equations for three-wheelers in selected states

Variable	Andhra Pradesh			Bihar			Delhi			Gujarat			Karnataka			Maharashtra		
	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)
Coefficient	-85253.96	0.00000031	0.77	-58675.34	0.00000041		-8188.35	0.00000042		-105869.20	0.00000007		-113341.00	0.00000058	0.72	-111183.00	0.00000039	1.58
Std. error	43617.50	0.00000008	0.17	9710.85	0.00000005		5834.40	0.00000003		26197.58	0.00000001		22595.89	0.00000005	0.16	46692.25	0.00000005	0.22
t-Statistic	-1.98	4.02	4.44	-6.04	8.58		-1.40	13.09		-4.04	10.71		-5.02	10.84	4.49	-2.38	7.17	-3.45
Prob.	0.07	0.00	0.00	0.00	0.00		0.18	0.00		0.00	0.00		0.00	0.00	0.00	0.03	0.00	0.00
R-square			0.92		0.80			0.90			0.86			0.98				0.98
N			19		20			20			20			19				18

C stands for the constant term, AR for auto regression, N for number of observations considered

Table 6 Econometric equations for three-wheelers in selected states

Variable	Rajasthan			Tamil Nadu			Uttar Pradesh			West Bengal			Rest of India		
	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)
Coefficient	-15732.07	0.00000013		-60565.77	0.00000025		-85058.03	0.00000019		-15782.39	0.00000006	0.37	-375855.40	0.00000028	0.59
Std. error	1712.84	0.00000001		4508.66	0.00000001		9962.92	0.00000002		1766.44	0.00000004	0.26	62044.45	0.00000003	0.21
t-Statistic	-9.18	23.29		-13.43	26.10		-8.54	12.59		-8.93	13.88	1.43	-6.06	10.25	2.84
Prob.	0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00	0.18	0.00	0.00	0.01
R-square			0.97		0.97			0.90			0.97				0.97
N			20		20			20			16				19

C stands for the constant term, AR for auto regression, N for number of observations considered

Table 7 Econometric equations for taxis in selected states

Variable	Andhra Pradesh			Bihar			Delhi			Gujarat			Karnataka		
	C	NDP	AR(1)	AR(2)	C	NDP	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)
Coefficient	-14368.35	0.00000006	1.46	-0.81	-34478.63	0.00000027	4243.5	0.000000042	0.57	-15162.80	0.000000078		-10626.82	0.000000068	0.61
Std. error	5119.65	0.00000001	0.26	0.36	5466.88	0.00000003	524.23	0.000000002	0.20	1983.92	0.000000005		3084.94	0.000000008	0.20
t-Statistic	-2.81	5.30	5.62	-2.25	-6.31	10.09	8.09	16.8698	2.86	-7.64	16.48		-3.44	8.62	3.02
Prob.	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.0000	0.01	0.00	0.00		0.00	0.00	0.01
R-square				0.97		0.85			0.99		0.94				0.96
N				18		20			19		20				19

C stands for the constant term, AR for auto regression, N for number of observations considered

Table 8 Econometric equations for taxis in selected states

Variable	Maharashtra			Rajasthan			Tamil Nadu			Uttar Pradesh			West Bengal			Rest of India		
	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)	C	NDP	AR(1)
Coefficient	12540.08	0.000000045	117000000.00	0.000000013	1.00	-32867.56	0.00000011	0.87	-30648.11	0.00000007	1898.31	0.00000007	-81287.14	0.000000082	0.39			
Std. error	2947.20	0.000000003	74100000000.00	0.000000006	0.04	31646.88	0.00000004	0.16	3438.67	0.00000001	2743.52	0.00000001	9854.15	0.000000004	0.22			
t-Statistic	4.25	13.39	0.00	2.25	25.77	-1.04	2.59	5.34	-8.91	13.96	0.69	11.18	-8.25	18.23	1.76			
Prob.	0.00	0.00	1.00	0.04	0.00	0.31	0.02	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.10			
R-square					0.99			0.92		0.92		0.87			0.98			
N		20			19			19		20		20			19			

C stands for the constant term, AR for auto regression, N for number of observations considered

Table 9 Econometric equations for buses in selected states

Variable	Andhra Pradesh			Bihar			Delhi			Gujarat			Karnataka			AR(1)
	C	NDP	NDP	C	NDP	NDP	C	LOG(NDP)	AR(1)	C	NDP	NDP	C	NDP	NDP	
Coefficient	-13436.45	0.00000009	0.00000009	-5204.69	0.00000010	0.00000010	-11.11	0.82	0.59	1503.68	0.000000061	0.000000061	-5859.13	0.000000010	0.000000010	0.40
Std. error	3425.93	0.00000001	0.00000001	2051.72	0.00000001	0.00000001	1.97	0.08	0.16	2005.85	0.000000005	0.000000005	2587.07	0.000000001	0.000000001	0.23
t-Statistic	-3.92	11.93	11.93	-2.54	10.05	10.05	-5.64	10.77	3.65	0.75	12.71	12.71	-2.26	13.82	13.82	1.73
Prob	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.04	0.00	0.00	0.10
R-square		0.89	0.89		0.85	0.85			0.99		0.90	0.90				0.97
N			20			20			19			20				19

C stands for the constant term, AR for auto regression, N for number of observations considered

Table 10 Econometric equations for buses in selected states

Variable	Maharashtra			Rajasthan			Tamil Nadu			Uttar Pradesh			West Bengal			Rest of India		
	C	NDP	AR(1)	C	NDP	NDP	C	NDP	NDP	C	NDP	AR(1)	C	NDP	NDP	C	NDP	NDP
Coefficient	-2700.98	0.000000044	0.69	-12101.54	0.000000124	0.000000124	2438.54	0.000000053	588.95	0.000000036	0.41	0.41	7381.93	0.000000032	-37455.81	0.000000007	0.000000007	0.000000007
Std. error	7915.49	0.000000008	0.20	1457.68	0.000000005	0.000000005	2060.44	0.000000004	2454.41	0.000000004	0.25	0.25	1636.74	0.000000004	13223.72	0.000000001	0.000000001	0.000000001
t-Statistic	-0.34	5.57	3.44	-8.30	25.29	25.29	1.18	12.39	0.24	10.23	1.65	1.65	4.51	8.86	-2.83	10.63	10.63	10.63
Prob.	0.74	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.81	0.00	0.12	0.12	0.00	0.00	0.01	0.00	0.00	0.00
R-square			0.94		0.97	0.97		0.90	0.90		0.95	0.95		0.81			0.86	0.86
N			19			20			20			19			20			20

C stands for the constant term, AR for auto regression, N for number of observations considered

Table11 Econometric equations for LCVs for states

Dependent Variable: LOG(S?)				
Method Pooled Least Squares				
Sample (adjusted) 1993 2001				
Included observations 9 after adjusting endpoints				
Number of cross-sections used 11				
Total panel (balanced) observations 88				
Convergence achieved after 11 iteration(s)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-10.6690	7.5190	-1.4189	0.1598
T2	0.2177	0.0570	3.8217	0.0003
T3	0.5755	0.0702	8.1994	0.0000
T4	0.7279	0.0696	10.4525	0.0000
T5	0.6673	0.0571	11.6837	0.0000
LOG(NDP?)	0.6971	0.2719	2.5637	0.0122
AR(1)	0.8917	0.0445	20.0349	0.0000
R-squared	0.9455	Mean dependent var		8.6946
Adjusted R-squared	0.9415	S.D. dependent var		0.8288
S.E. of regression	0.2005	Sum squared resid		3.2566
F-statistic	234.2493	Durbin-Watson stat		2.3011
Prob (F-statistic)	0.0000			

S stands for sales of LCVs, T1-T4 for time dummies, and AR for auto regression

Table12 Econometric equations for trucks for states

Dependent Variable: LOG(S?)				
Method Pooled Least Squares				
Sample (adjusted) 1993 2000				
Included observations 8 after adjusting endpoints				
Number of cross-sections used 11				
Total panel (balanced) observations 77				
Convergence achieved after 7 iteration(s)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-10.5505	3.0033	-3.5129	0.0008
LOG(NDP?)	0.6912	0.1098	6.2935	0.0000
T2	0.4081	0.0812	5.0244	0.0000
T3	0.7326	0.0968	7.5684	0.0000
T4	0.9034	0.0963	9.3846	0.0000
T5	0.4921	0.0812	6.0621	0.0000
T7	0.4417	0.0667	6.6201	0.0000
AR(1)	0.5956	0.0898	6.6304	0.0000
R-squared	0.8553	Mean dependent var		8.6317
Adjusted R-squared	0.8407	S.D. dependent var		0.6355
S.E. of regression	0.2537	Sum squared resid		4.4399
F-statistic	58.2822	Durbin-Watson stat		2.1048
Prob (F-statistic)	0.0000			

S stands for sales of trucks, T1-T7 for time dummies, and AR for auto regression

Annex 3.1 Health effects of CO at different concentrations

Concentration	Exposure time	Observed effects	Other effects	Remarks
40 ppm	>2 hours	Adversely effects a persons ability to make judgements	Developmental toxicity: Exposure of pregnant women to CO has been linked to low birth weight, cardio megal, delay in behavioural development, disruption in cognitive functions and sometimes even Sudden Infant Death Syndrome (SIDS)	Clinical data indicate that CO from smoking and environmental or occupational exposures may contribute to cardiovascular mortality and to the early course of myocardial infarction.
100 ppm	3.5 hours	Impairment of visual perception, of manual dextenty, of learning, and impairment of performance of certain intellectual tasks		Moreover, smokers or people documented with coronary heart disease are highly susceptible to the adverse effects of CO.
175 ppm	2-4 hours	Headaches		
873 ppm	2-4 hours	Strong headache, nausea, fatigue, dizziness, increase in pulse rate leading to convulsions and coma	Cerebro-vascular and behavioral effect: Due to increase in cerebral blood flow as a result of hypoxia it may lead to head injury, atherosclerosis, hypertension.	
1598 ppm	1-2 hours	Death		

Source CPCB 2001(a,b); Stern AC (ed) 1977; World Bank 1997, CPCB 2002

Annex 3.2 Health effects of O₃ at different concentrations

Concentration	Exposure	Effects	Other effects
1 ppm	2 hours	Reduction in vital capacity and maximal breathing capacity	Short term adverse effect include eye, nose and throat irritation, coughing, throacic pain, increased mucous production, chest tightness, lassitude, malaise and nausea. Systemic effects: Spheerng of erythrocytes, chromosome breakage in lymphocytes, retardation of deoxygenation of haemoglobin, premature aging.
0.5 ppm	3 hours per day for 6 weeks	Progressive decrease in 1 second forced expiratory volume	

Source. CPCB 2001(a,b); Stern AC (ed) 1977; World Bank 1997, CPCB 2002

Annex 3.3 Health effects of NO₂ at different concentrations

Concentration	Exposure time	Observed effect	Other effects	Remarks
2.5 ppm	<2 hours	Pronounced decrease in pulmonary function	Exposure in large doses can result in dysfunction of host defences by causing structural alteration in ciliated cells of mucociliary escalator, in alveolar macrophages, decrease in production of sulphur dioxide anion radical (bactencidal), decrease in phagocytosis.	The adverse effects are seen after the exposure has ceased
5.0 ppm	15 minutes	Decreased diffusion capacity		
50 ppm	1 minute	Respiratory tract irritation		
0.1 ppm	1-3 years (continuous exposure)	Increase incidence of bronchitis, emphysema, oedema		
0.4-2.7 ppm	180 days(long-term intermittent exposure)	Increase in blood lipids, lipoproteins and cholesterol		

Source. CPCB 2001(a,b); Stern AC (ed) 1977; World Bank 1997; CPCB 2002

Annex 3.4 Health effects of particulates

Type	Description	Source	Health effects and remarks
Particulates	Any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules (about 0.0002 µm in diameter), but smaller than about 500 µm. Extremely diverse and complex due to wide range of sizes, chemical composition and atmospheric concentration.	Anthropogenic sources of particulate matter (PM) include thermal power plants, industries, commercial and residential facilities, construction sites, stone crushing, burning of wood, motor vehicles using fossil fuels Natural sources Wind-blown soil, dust from tilled fields, unpaved roads etc. volcanic ash, Forest fires, sea salt and pollen.	The harmful effects, if any, of the particles depend on their chemical and mineralogical composition, solubility and biological activity Known to cause bronchitis and respiratory related illnesses. Low birth weights have been established as a risk factor for acute respiratory infections
SPM/ TSP	Suspended particulate matter or total suspended particulates are particulates that have diameter less than 100 µm. Tend to settle near their emission source	Anthropogenic sources. Contribution arising from fossil fuel burning industrial processes, vehicular pollution Natural sources Sea salt, soil dust, volcanic particles and smoke from forest fires	
RSPM or PM ₁₀	Particulates having diameter 10 µm or less PM ₁₀ remains longer in the atmosphere because of its low settling velocity.	Have their origin from road dust, vehicular exhausts (diesel and petrol vehicles), wind blown dust, agriculture, construction and fireplaces	PM ₁₀ have their primary source linked to the transportation sector where the particulates emissions are less than 10 µm. Increased vehicular population have shown an increase particulates They can get deposited in the extrathoracic part of the respiratory tract through nasal breathing Particulates in the size range between 2.5 µm to 10 µm get deposited near the fine airways PM _{2.5} can evade human respiratory systems defence system and reach lung tissue and soluble particles be absorbed into the blood system.
Fine Particulates	Particulates having diameter 2.5 µm or less are termed fine particulates.	Formed by various processes Particles in the 0.005 - 0.05 µm ranges are usually formed by condensation of vapours at high temperature or chemical processes Particles in the 0.05-2 µm range are usually formed by coagulation of smaller particles. PM _{2.5} are emitted from fuel combustion in motor vehicles, process combustion and from industrial sources, residential and agricultural burning. PM _{2.5} from chemical reactions that involve such gases as SO ₂ , NO _x and VOC. Result of solidification of volatile metal salts as crystals following cooling of hot exhaust gases from vehicles in ambient air. PM _{2.5} may also be formed from sulphates, which generated by conversion from primary sulphur emissions.	The effects seen with it are pneumonia, asthma, and bronchitis

Annex 3.5 Health effects of SO₂ at different concentrations

Concentration	Exposure time	Observed effects	Other effects	Remarks
0.0035-0.1 ppm	>3 years	Excessive acute respiratory disease in communities heavily polluted with SO ₂ and sulphates	Chronic ambient exposure may result in increased risk of morbidity and/or mortality and also of chronic bronchitis.	The adverse effects of SO ₂ is aggravated when in combination to particulates and more pronounced in persons suffering from asthma
0.52 ppm	15 minutes	Increased eye sensitivity to light during dark adaptation		
1.6 ppm	-	Lowest concentration resulting in bronchoconstriction		
2.0-5.0 ppm	3-10 minutes	Increased airway resistance		

Source: CPCB 2001(a,b), Stern AC (ed) 1977, World Bank 1997, CPCB 2002

Annex 3.6 Sources of pollutants

Source	Pollutants				
	Particulate matter	SO ₂	NO _x	CO	Hydrocarbons
<i>Industrial</i>					
Power plant (coal)	++++	+++	+++	-	-
Sulphuric acid	+++	++++	-	-	-
Super phosphate	++++	-	-	-	-
Cement	+++	-	++++	-	-
Carbon black	+	++	++	+++	+
Oil refinery	+++	++++	++	+	++
Aluminium	+++	+	++	+	++
Copper and zinc	++++	++++	++	-	-
Iron and steel	+++	++	+++	+++	++
Brick kilns	+	+	++	++	++
<i>Vehicular</i>					
Petro-driven	-	++	++	++++	++++
Diesel-driven	+++	++	++++	-	-
<i>Domestic</i>					
Coal	++	++	+	++	++
Wood	++	++	+	++	++
Kerosene	+	++	++	+	++
Biogas	-	-	-	+	-
LPG	-	-	+	-	-
<i>Others</i>					
Refuse burning	++	+	++	+	-
Domestic dumps	++	+	++	+	-
Construction	+++	-	-	-	-
Activities					
Resuspension of dust from roads	++++	-	-	-	-

+ Sign indicates emission strength, - Sign indicates absence or near absence

Source: CPCB 2000a

Annex3.7 Regulated pollutants

Pollutant	Causes/remarks	Sources	Total worldwide anthropogenic emissions	Emissions from the transportation sector	Health effects
CO	Incomplete combustion of carbonaceous fuels due to lack of oxygen supply	Anthropogenic sources: Vehicular sources, thermal power plants, heating for industrial facilities, and incinerators. Minor sources. Solid waste disposal sites and refuse burning	In 1995 350 million tonnes, 59% of which contributed by the transportation sector alone.	The USEPA (United States Environmental Protection Agency) has estimated that about 70% of CO emissions are from transportation sector with almost all of that coming from vehicles	CO is absorbed through the lungs It reduces the blood's capacity to transport available oxygen to the tissues Lowers the oxygen level in blood CO uptake impairs perception and thinking Slows reflexes, may cause drowsiness, angina, unconsciousness or death (World Bank 1997)
NO _x	NO and NO ₂ together are generally expressed as NO _x . Their emissions are governed by 1) Availability of oxygen and 2) High temperature NO gets oxidised in the atmosphere to form NO ₂	Anthropogenic sources Fuel combustion in motor vehicles, power stations and furnaces	World-wide anthropogenic NO _x emissions for 1995 were estimated at 93 million tonnes	(43 %) of this or 33 million tonnes attributed to be from the transportation sector	It is absorbed into the mucous membrane of the respiratory tract. Exposure to NO ₂ is with increased susceptibility to respiratory infection increases airway resistance in asthmatics and decreases pulmonary function Possible increase in acute respiratory infections and bronchitis morbidity in children Produce brown haze in city air Causes corrosion

Pollutant	Causes/remarks	Sources	Total worldwide anthropogenic emissions	Emissions from the transportation sector	Health effects
SO ₂	SO ₂ emissions are linked to the sulphur content of the fuel. Hence, SO ₂ gases are formed when fuel-containing sulphur, such as coal and oil, is burned. They are also formed in petroleum refineries, cement manufacturing and metal processing facilities.	Anthropogenic sources Burning of sulphur containing fuels like coal and oil Non combustion sources, industrial facilities that derive their products from raw materials like metallic ore, coal, and crude oil.	Over 65% of SO ₂ released to the air, more than 13 million tons per year, comes from electric utilities, especially those that burn coal.	The transportation sector alone at a global level contributes to about 2 to 6 percent of the global SO ₂ emissions. (WB 1997).	Combined with smoke, increase risk and effects respiratory diseases. Causes suffocation and irritation of throat and eyes
Pb	Tetraethyl lead, used as an anti-knock agent in petrol is released into the atmosphere as fine particles when petrol is burnt. Other sources	Anthropogenic sources Emission from motor vehicles, lead smelters, waste incinerators, utilities and lead acid battery manufacturers.	-	-	Adversely affects the human nervous system. Causes anaemia, brain dysfunctions and kidney damage.
O ₃	Mainly derivative: products of atmospheric reactions between other pollutants. Ozone is a natural and essential constituent of the upper atmosphere. Source CPCB. 2000a	Emissions from motor vehicles. Photochemical reactions of nitrogen oxides and reactive hydrocarbons	-	-	Cause eye irritation and impaired pulmonary function in diseased persons. Corrode materials and reduces visibility. Ozone is one of the most damaging pollutants for plants

Annex 3.8 Some unregulated pollutants

Pollutant	Causes/Remarks	Sources	Health effects
Hydrocarbons	Group of compounds consisting of carbon and hydrogen. In air quality studies, the term hydrocarbon is extended to include a variety of other volatile organic compounds (VOCs) such as alcohols and aldehydes. Several hundred different hydrocarbons (e.g. methane, ethane, ethylene, pentane, benzene) have been distinguished with detailed proportions depending on combustion conditions	HC emissions from motor vehicles occur from unburned fuel or from partial combustion of fuel	Most hydrocarbons are not directly harmful to health at concentrations found in the ambient air When they undergo chemical reactions (except methane) in the troposphere they form O_3 and NO_2 which are considered as health and environmental hazards
Toxic hydrocarbons	Benzene, 1, 3-butadiene, aldehydes and polynuclear aromatic hydrocarbons are few of the major toxic HCs emitted by motor vehicles.		This group represents about 8 percent of the global emissions of VOCs and are mutagenic in nature
a)Benzene	Benzene in exhaust originates directly as it is present in petrol as well as from partial combustion of aromatic compounds present in petrol like Xylene and Toluene	Occurs in natural Emissions from manmade sources are significant Direct evaporative emissions Vehicular exhaust	Early manifestation of toxicity are anaemia leucocytopenia or thromocytopenia. It is a known human carcinogen Long term exposure causes leukemia. Exposures to benzene is linked to genetic changes, increased proliferation of bone marrow cells and occurrence of certain chromosomal aberrations WHO estimates a 4 in 1 million risk of leukaemia on exposure to benzene to a concentration of $1\text{g}/\text{m}^3$ (CPCB 2000b) According to the U S EPA, roughly 70.2% of the total benzene emissions come from vehicles (World Bank 1997, World Bank 1997a) Out of the total benzene levels in air, about 85-90% of its emissions come from exhaust and the remainder comes directly from petrol evaporation and through distribution losses (World Bank 1997, World Bank 1997a)
b) 1,3 butadiene	Formed in vehicle exhaust due to the incomplete combustion of fuel and is not present in vehicle evaporative and refuelling emissions	Mobile sources account for nearly 94% of the total 1,3 Butadiene emissions (Kush 2001)	Transformation of 1,3 butadiene in the atmosphere result in the formation of formaldehyde and acrolein, species which are themselves toxic and/or irritants UK expert panel on air quality standards has recommended 1ppb ($2.2\text{g}/\text{m}^3$) as the rolling annual mean for butadiene. WHO air quality guidelines recommend a maximum concentration of $0.1\text{mg}/\text{m}^3$ (for a period of 30minutes)

Pollutant	Causes/Remarks	Sources	Health effects
c) Formaldehyde	Not a component of evaporative emissions. Formaldehyde exhibits extremely complex atmospheric behavior. Though difficult to quantify, it appears that mobile source contribution of formaldehyde in the ambient air is approx. 30%.	Vehicular exhausts petrol and diesel fuelled vehicles Also formed by the atmospheric oxidation of virtually all organic species	Aldehydes are absorbed in the respiratory and gastrointestinal tracts and metabolized. Adverse health effects include eye and nose ³ irritation at a concentration of 0.06 mg/m ³ Irritation of mucous membranes and alteration in respiration, coughing, nausea, and shortness of breath. Threshold for tissue damage is about 1 mg/m ³ Occupational exposure to formaldehyde is associated with risk of cancer.
d) Acetaldehyde	vehicle exhaust due to incomplete combustion of fuel. 40% of the acetaldehyde in ambient air may be attributable to mobile sources.	Acetaldehyde is produced from combustion from vehicle exhaust, from coal refining, wood burning or other types of incomplete combustion, such as in smoke from cigarettes.	Acetaldehyde causes health effects from both short term or acute exposures, such as in spills, and also long term or chronic exposures, such as repeated occupational exposures. Individuals also react differently to different levels of exposure. Acute exposure to acetaldehyde by inhalation may cause irritation of the eyes, nose, throat and lungs. At higher exposures, there may be coughing, pulmonary edema and respiratory paralysis and death.

Annex 3.9 Ambient air quality ($\mu\text{g}/\text{m}^3$)

Air pollutants	Time weighted average	WHO, 1999	India, 1994			USEPA	UK	Japan
			Industrial	Residential	Sensitive	July 1997	1997	
NO _x	Annual Average	40	80	60	15	100	21 PPB ^a	-
	24 hr	-	120	80	30	-	-	75-113
	1 hr	200	-	-	-	-	150 PPB	-
SO ₂	Annual Average	50	80	60	15	80	-	-
	24 hr	125	120	80	30	365	-	-
	3 hr	-	-	-	-	1300	-	-
	1 hr	-	-	-	-	-	100 PPB	286
	10 min	500	-	-	-	-	(15 min)	-
CO	8 hr	10000	5000	2000	1000	10000	10 PPM ^b	-
	1 hr	30000	10000	4000	2000	40000	-	22900
	30 min	60000	-	-	-	-	-	-
	15 min	100000	-	-	-	-	-	-
Pb	Annual Average	0.5	1	0.75	0.5	1.5	0.5	-
	24 hr	-	1.5	1	0.75	-	-	-
PM ₁₀	Annual Average	-	120	60	50	50	-	-
	24 hr	-	150	100	75	150	50	100
SPM	Annual Average	*	360	140	70	-	-	-
	24 hr	*	500	200	100	-	-	-
PM _{2.5}	Annual Average	-	-	-	-	15	-	-
	24 hr	-	-	-	-	65	-	-
Ozone (O ₃)	8 hr	120	-	-	-	157	50 PPB	120
	1 hr	-	-	-	-	235	-	-
Ammonia	Annual Average	-	-	100	-	-	-	-
	24 hr	-	-	400	-	-	-	-

* No definite guidelines mentioned, ^aPPB – parts per billion, ^bPPM – parts per million

Source: CPCB 2000a

Annex 3.10 Major air pollution related diseases in India

- (1) ACUTE RESPIRATORY DISEASE
12 % deaths; 13% of national burden of disease (NBD). Largest fraction in the world. Indian acute respiratory infection (ARI) in children alone under 5 is responsible for more than 2% of entire global burden of disease (GBD)
- (2) CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD)
1.5% deaths; 0.9% of NBD
- (3) LUNG CANCER
0.4% deaths; 0.1% of NBD
- (4) ASTHMA
0.2% deaths, 0.5% of NBD
- (5) TUBERCULOSIS.
8% deaths, 5% of NBD, Largest in the world
- (6) PERINATAL:
6% deaths; 7.5% of NBD, Largest in the world
- (7) CARDIO VASCULAR DISEASE
17% deaths, 5% of NBD
- (8) BLINDNESS.
0% of deaths; 1% of NBD, Largest in the world

Source. CPCB. 2001b, Smith 2000.

ex 4.1 Emission standards in the European Union

At first, vehicular emissions regulations in the European Union (EU) were formulated primarily by the United Nations Economic Commission for Europe (UN-ECE). The ECE was supported by most European nations, including many Eastern European countries. Its role was to produce model standards, which could be adopted by member nations, but it had no power to enforce compliance. In its early years, the European Union generally adopted regulations, which were technically identical with the ECE equivalents. This position has changed over time. The European Community, the European Union, has gradually assumed a major role in formulating automotive emissions standards. In the early 1980s, more stringent emission standards were passed first for large cars and then for smaller cars. This process meant that catalytic converters would be required on new petrol fuelled cars, and these culminated in the EC directives for Euro I and Euro II standards. The European Union regulations, published as Directives, have the force of law within EU Member States under the provisions of the Treaty of Rome. With the introduction of the 'Consolidated Emissions Directive', implementation has become mandatory for all EU member states. It is no longer left to the discretion of individual national governments. A four-year transitional period till January 1999 was agreed for the environmental legislation for the countries that had joined recently. After this period, the limits had to be harmonized or renegotiated.

ht-duty vehicles

Light duty vehicles (passenger cars) were the first to be regulated under the ECE process. Their limit values have been subsequently been amended. The EU light-duty vehicle standards are different for diesel and petrol vehicles. Diesels have lower CO standards but are allowed higher NO_x. Petrol vehicles are exempted from PM standards. The 2000/2005 standards were accompanied by an introduction of more stringent fuel quality rules that require a minimum diesel Cetane Number of 51 (year 2000), maximum diesel sulphur content of 350 ppm in 2000 and 50 ppm in 2005, and maximum petrol (petrol) sulphur content of 150 ppm in 2000, and 50 ppm in 2005. Light commercial vehicles have been further classified according to their mass, to reflect the differences in their power train layouts and body shapes. The standards for new passenger cars and light commercial vehicles are summarized in Tables A4.1 and A4.2, respectively.

Table A4.1 EU emission standards for passenger cars, g/km

Tier	Year	CO	HC	HC+NOx	NOx	PM
<i>Diesel</i>						
Euro I	1992	2.72	-	0.97	-	0.14
Euro II - indirect injection	1996	1.0	-	0.7	-	0.08
Euro II - direct injection	1999	1.0	-	0.9	-	0.10
Euro III	2000.01	0.64	-	0.56	0.50	0.05
Euro IV	2005.01	0.50	-	0.30	0.25	0.025
<i>Petrol</i>						
Euro III	2000.01	2.30	0.20	-	0.15	-
Euro IV	2005.01	1.0	0.10	-	0.08	-

Source <http://www.dieselnet.com/standards/eu/ld.html> as on 3 September 2002

Table A4.2 EU emission standards for light commercial vehicles, g/km

Class	Tier	Year	CO	HC	HC+NOx	NOx	PM
<i>Diesel</i>							
N1 <1305 kg	Euro I	1994.10	2.72	-	0.97	-	0.14
	Euro II	1998.01	1.0	-	0.60	-	0.10
	Euro III	2000.01	0.64	-	0.56	0.50	0.05
	Euro IV	2005.01	0.50	-	0.30	0.25	0.025
	Euro I	1994.10	5.17	-	1.40	-	0.19
N2 1305-1760 kg	Euro II	1998.01	1.2	-	1.1	-	0.15
	Euro III	2002.01	0.80	-	0.72	0.65	0.07
	Euro IV	2006.01	0.63	-	0.39	0.33	0.04
	Euro I	1994.10	6.90	-	1.70	-	0.25
N3 >1760 kg	Euro II	1998.01	1.35	-	1.3	-	0.20
	Euro III	2002.01	0.95	-	0.86	0.78	0.10
	Euro IV	2006.01	0.74	-	0.46	0.39	0.06
<i>Petrol</i>							
N1 <1305 kg	Euro I	1994.10	2.72	-	0.97	-	-
	Euro II	1998.01	2.2	-	0.50	-	-
	Euro III	2000.01	2.3	0.20	-	0.15	-
	Euro IV	2005.01	1.0	0.1	-	0.08	-
N2 1305-1760 kg	Euro I	1994.10	5.17	-	1.40	-	-
	Euro II	1998.01	4.0	-	0.65	-	-
	Euro III	2002.01	4.17	0.25	-	0.18	-
	Euro IV	2006.01	1.81	0.13	-	0.10	-
N3 >1760 kg	Euro I	1994.10	6.90	-	1.70	-	-
	Euro II	1998.01	5.0	-	0.80	-	-
	Euro III	2002.01	5.22	0.29	-	0.21	-
	Euro IV	2006.01	2.27	0.16	-	0.11	-

Note: N1, N2 and N3 are weight classes for the vehicles.

For Euro I/II the weight classes were N1 (<1250 kg), N2 (1250-1700 kg), N3 (>1700 kg).

Source <http://www.dieselnet.com/standards/eu/ld.html> as on 3 September 2002

The useful vehicle life for the purpose of emission regulations is 80,000 km through the Euro III stage, and 100,000 km beginning at the Euro IV stage (2005). The 2000/2005 regulations include several additional provisions:

- EU member states may introduce tax incentives for early introduction of 2005 compliant vehicles.
- Requirement for on-board emission diagnostics systems (OBD) phased-in between 2000 and 2005.

- Requirement for low temperature emission test (7 °C) for petrol vehicles effective 2002.

Heavy-duty vehicles

For new heavy-duty diesel engines, the environment regulations are specified till Euro V. The Euro II regulations, which came to power in 1996, applied to both heavy-duty highway diesel engines and urban buses. The urban bus standards however, were voluntary. In 1999, the European Parliament and the Council of Environment Ministers adopted the final Euro III standard and also adopted Euro IV and V standards for the year 2005/2008. The standards also set specific, stricter values for extra low emission vehicles (also known as 'enhanced environmentally friendly vehicles' or EEVs) in view of their contribution to reducing atmospheric pollution in cities. The details of the emission standards for diesel and gas engines and heavy-duty diesel engines are given in Tables A4.3 and A4.4, respectively.

Table A4.3 Emission standards for diesel and gas engines, ETC test, g/kWh

Tier	Date and category	Test cycle	CO	NMHC	CH ₄ ^a	NO _x	PM ^b
Euro III	1999.10, EEVs only	ETC	3.0	0.40	0.65	2.0	0.02
	2000.10	ETC	5.45	0.78	1.6	5.0	0.16
							0.21 ^c
Euro IV	2005.10		4.0	0.55	1.1	3.5	0.03
Euro V	2008.10		4.0	0.55	1.1	2.0	0.03

^afor natural gas engines only

^bnot applicable for gas fuelled engines at the year 2000 and 2005 stages

^cfor engines of less than 0.75 dm³ swept volume per cylinder and a rated power speed of more than 3000 min⁻¹

EEV - Enhanced environmentally friendly vehicle; ESC - European Stationary Cycle

Source <http://www.dieselnet.com/standards/eu/hd.html> as on 3 September 2002

Table A4.4 EU Emission Standards for heavy duty diesel engines, g/kWh (smoke in m⁻¹)

Tier	Date & Category	Test Cycle	CO	HC	NO _x	PM	Smoke
Euro I	1992, <85 kW	ECER-49	4.5	1.1	8.0	0.612	
	1992, >85 kW		4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	1999.10, EEVs only	ESC & ELR	1.5	0.25	2.0	0.02	0.15
	2000.10	ESC & ELR	2.1	0.66	5.0	0.10	0.8
						0.13 [*]	
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5

^{*}for engines of less than 0.75 dm³ swept volume per cylinder and a rated power speed of more than 3000 min⁻¹

EEV - Enhanced environmentally friendly vehicle; ESC - European Stationary Cycle; ETC - European Transient Cycle; ELR - European Load Response test; ECER-49 - steady-state diesel engine test cycle introduced by ECE Regulation No.49.

Source <http://www.dieselnet.com/standards/eu/hd.html> as on 3 September 2002

It is expected that the emission limit values set for 2005 and 2008 will require all new diesel-powered heavy duty vehicles to be fitted with exhaust gas after-treatment devices, such as particulate traps and DeNO_x catalysts. The 2008 NO_x standard will be reviewed by 31 December 2002 and either confirmed or modified, depending on the available emission control technology.

Changes in the engine test cycles have been introduced in the Euro III standard (year 2000). The old steady state engine test cycle ECE R-49 will be replaced by two cycles: a stationary cycle ESC (European Stationary Cycle) and a transient cycle ETC (European Transient Cycle). Smoke opacity is measured on the ELR (European Load Response) test.

For the type approval of new vehicles with diesel engines according to the Euro III standard (year 2000), manufacturers have the choice between either of these tests. For type approval according to the Euro IV (year 2005) limit values and for EEVs, the emissions have to be determined on both the ETC and the ESC/ELR tests. Emission standards for diesel engines that are tested on the ETC test cycle, as well as for heavy-duty gas engines, are summarized in the Tables A4.3 and A4.4 respectively.

Annex 4.2 US emission standards

Cars and light-duty vehicles

Federal standards

There are two sets of standards based on Federal Test Procedures (FTP), Tier 1 and Tier 2 that have been defined for light-duty vehicles in the Clean Air Act Amendments of 1990. The Tier 1 regulations were fully implemented in 1997. The Tier 2 standards were adopted on 21 December 1999, to be phased-in beginning in 2004.

Tier 1 Standards

Tier 1 light-duty standards apply to all new light duty vehicles (LDV), such as passenger cars, light duty trucks, sport utility vehicles (SUV), minivans and pick-up trucks. The LDV category includes all vehicles of less than 8500 lb gross vehicle weight rating, or GVWR (i.e., vehicle weight plus rated cargo capacity).

LDVs are further divided into the following sub-categories:

- Passenger cars
- Light light-duty trucks (LLDT), below 6000 lbs GVWR
- Heavy light-duty trucks (HLDT), above 6000 lbs GVWR

The Tier 1 standards were phased-in progressively between 1994 and 1997. They apply to a full vehicle useful life of 100,000 miles (effective 1996). The regulation also defines an intermediate standard to be met over a 50,000 mile period. The difference between diesel and petrol car standards is a more relaxed NO_x limit for diesels, which applies to vehicles through model year 2003. The details of the emission standards are given in the Table A4.5.

Table A4.5 EPA Tier 1 emission standards for passenger cars and light-duty trucks, FTP 75, g/mi

Category	50,000 miles/5 years						100,000 miles/10 years ¹					
	THC	NMHC	CO	NO _x		PM	THC	NMHC	CO	NO _x		PM
				diesel	petrol					diesel	petrol	
Passenger cars	0.41	0.25	3.4	1	0.4	0.08	-	0.31	4.2	1.25	0.6	0.1
LLDT, LVW	-	0.25	3.4	1	0.4	0.08	0.8	0.31	4.2	1.25	0.6	0.1
LLDT, LVW	-	0.32	4.4	-	0.7	0.08	0.8	0.4	5.5	0.97	0.97	0.1
HLDT, ALVW	0.32	-	4.4	-	0.7	-	0.8	0.46	6.4	0.98	0.98	0.1
HLDT, ALVW	0.39	-	5	-	1.1	-	0.8	0.56	7.3	1.53	1.53	0.12

¹ Useful life 120,000 miles/11 years for all HLDT standards and for THC standards for light duty truck

LVW - loaded vehicle weight (curb weight + 300 lbs)

ALVW - adjusted LVW (the numerical average of the curb weight and the GVWR)

LLDT - light light-duty truck (below 6,000 lbs GVWR)

HLDT - heavy light-duty truck (above 6,000 lbs GVWR)

Tier 2 standards

The Tier 2 standards bring significant emission reductions relative to the Tier 1 regulation. In addition to more stringent numerical emission limits, the regulation introduces a number of important changes that make the standard more stringent for larger vehicles. Under the Tier 2 standard, the same emission standards apply to all vehicle weight categories, i.e., cars, minivans, light duty trucks, and SUVs have the same emission limit. Since light-duty emission standards are expressed in grams of pollutants per mile, large engines (such as those used in light trucks or SUVs) will have to utilize more advanced emission control technologies than smaller engines in order to meet the standard.

In Tier 2, the applicability of light-duty emission standards has been extended to cover some of the heavier vehicle categories. The Tier 1 standards applied to vehicles up to 8500 lbs GVWR. The Tier 2 standard applies to all vehicles that were covered by Tier 1 and, additionally, to 'medium-duty passenger vehicles' (MDPV). The MDPV is a new class of vehicles that are rated between 8,500 and 10,000 GVWR and are used for personal transportation. This category includes primarily larger SUVs and passenger vans. Engines in

commercial vehicles above 8500 lbs GVWR, such as cargo vans or light trucks, will continue to certify to heavy-duty engine emission standards.

The emission limits that apply to all vehicles are fuel neutral. That is, vehicles fueled by petrol, diesel, or alternative fuels all must meet the same standards.

The Tier 2 tailpipe standards are structured into 8 certification levels of different stringency, called 'certification bins', and an average fleet standard for NO_x emissions. Vehicle manufacturers will have a choice to certify particular vehicles to any of the 8 bins. At the same time, the average NO_x emissions of the entire vehicle fleet sold by each manufacturer will have to meet the average NO_x standard of 0.07 g/mi.

Additional temporary certification bins (bin 9, 10, and an MDPV bin) of more relaxed emission limits will be available in the transition period. These bins will expire after 2008 model year.

The Tier 2 standards will be phased-in between 2004 and 2009. For new passenger cars and light LDTs, Tier 2 standards will phase-in beginning in 2004, with the standards to be fully phased in by 2007. For heavy LDTs and MDPVs, the Tier 2 standards will be phased-in beginning in 2008, with full compliance in 2009. During the phase-in period from 2004-2007, all passenger cars and light LDTs not certified to the primary Tier 2 standards will have to meet an interim average standard of 0.30 g/mi NO_x, equivalent to the current NLEV standards for LDVs. During the period 2004-2008, heavy LDTs and MDPVs not certified to the final Tier 2 standards will phase-in to an interim program with an average standard of 0.20 g/mi NO_x, with those not covered by the phase-in meeting a per-vehicle standard (i.e., an emissions 'cap') of 0.60 g/mi NO_x (for HLDTs) and 0.90 g/mi NO_x (for MDPVs).

The emission standards for all pollutants (certification bins) are given in Table A4.6. The vehicle 'full useful life' period has been extended to 120,000 miles.

Table A4.6 Tier 2 emission standards, FTP 75 g/mi

Bin#	50,000 miles					120,000 miles				
	NMOG	CO	NOx	PM	HCHO	NMOG	CO	NOx*	PM	HCHO
Temporary bins										
MDPV ^c						0.28	7.3	0.9	0.12	0.032
10 ^{a,b,d,f}	0.125 (0.160)	3.4 (4.4)	0.4	-	0.015 (0.018)	0.156 (0.230)	4.2 (6.4)	0.6	0.08	0.018 (0.027)
9 ^{a,b,e}	0.075 (0.140)	3.4	0.2	-	0.015	0.090 (0.180)	4.2	0.3	0.06	0.018
Permanent bins										
8 ^b	0.100 (0.125)	3.4	0.14	-	0.015	0.125 (0.156)	4.2	0.2	0.02	0.018
7	0.075	3.4	0.11	-	0.015	0.09	4.2	0.15	0.02	0.018
6	0.075	3.4	0.08	-	0.015	0.09	4.2	0.1	0.01	0.018
5	0.075	3.4	0.05	-	0.015	0.09	4.2	0.07	0.01	0.018
4	-	-	-	-	-	0.07	2.1	0.04	0.01	0.011
3	-	-	-	-	-	0.055	2.1	0.03	0.01	0.011
2	-	-	-	-	-	0.01	2.1	0.02	0.01	0.004
1	-	-	-	-	-	0	0	0	0	0

*Average manufacturer fleet NOx standard is 0.07 g/mi

^aBin deleted at end of 2006 model year (2008 for HLDTs)

^bThe higher temporary NMOG, CO and HCHO values apply only to HLDTs and expire after 2008

^cAn additional temporary bin restricted to MDPVs, expires after model year 2008

^dOptional temporary NMOG standard of 0.195 g/mi (50,000) and 0.280 g/mi (120,000) applies for qualifying

^eOptional temporary NMOG standard of 0.100 g/mi (50,000) and 0.130 g/mi (120,000) applies for qualifying

^f50,000 mile standard optional for diesels certified to bin 10

California Standards

Current Tier 1/Low Emission Vehicle (LEV) California emission standards extend through the year 2003. More stringent LEV II regulations would become effective from 2004.

Low emission vehicle (LEV) standards

The current California emission standards are expressed through the following emission categories:

- Tier 1
- Transitional Low Emission Vehicles (TLEV)
- Low Emission Vehicles (LEV)
- Ultra Low Emission Vehicles (ULEV)
- Super Ultra Low Emission Vehicles (SULEV)
- Zero Emission Vehicles (ZEV)

Table A4.7 summarizes the California ARB standards for new light-duty vehicles. Car manufacturers are required to produce a percentage of vehicles

which adhere to increasingly more stringent emission categories. After 2003, Tier 1 and TLEV standards will be eliminated as available emission categories. From 2004 onwards, the LEV II requirements begin.

Table A4.7 California emission standards for light-duty vehicles, FTP 75, g/mi

Category	50,000 miles/5 years					100,000 miles/10 years				
	NMOG ^a	CO	NOx	PM	HCHO	NMOG ^a	CO	NOx	PM	HCHO
Passenger cars										
Tier 1	0.25	3.4	0.4	0.08	-	0.31	4.2	0.6	-	-
TLEV	0.125	3.4	0.4	-	0.015	0.156	4.2	0.6	0.08	0.018
LEV	0.075	3.4	0.2	-	0.015	0.09	4.2	0.3	0.08	0.018
ULEV	0.04	1.7	0.2	-	0.008	0.055	2.1	0.3	0.04	0.011
LDT1, LVW <3,750 lbs										
Tier 1	0.25	3.4	0.4	0.08	-	0.31	4.2	0.6	-	-
TLEV	0.125	3.4	0.4	-	0.015	0.156	4.2	0.6	0.08	0.018
LEV	0.075	3.4	0.2	-	0.015	0.09	4.2	0.3	0.08	0.018
ULEV	0.04	1.7	0.2	-	0.008	0.055	2.1	0.3	0.04	0.011
LDT2, LVW >3,750 lbs										
Tier 1	0.32	4.4	0.7	0.08	-	0.4	5.5	0.97	-	-
TLEV	0.16	4.4	0.7	-	0.018	0.2	5.5	0.9	0.1	0.023
LEV	0.1	4.4	0.4	-	0.018	0.13	5.5	0.5	0.1	0.023
ULEV	0.05	2.2	0.4	-	0.009	0.07	2.8	0.5	0.05	0.013

^a NMHC for all Tier 1 standards

LVW - loaded vehicle weight (curb weight + 300 lbs)

LDT - light-duty truck

NMOG - non-methane organic gases

HCHO - formaldehyde

Source <http://www.dieselnet.com/standards/us/light.html#cal> as on 2 September 2002.

The same standards for gaseous pollutants apply to diesel- and petrol-fueled vehicles. PM standards apply to diesel vehicles only.

Emission standards for medium-duty vehicles are summarized in Table A4.8.

Low emission vehicle II (LEV II) standards

The LEV II emission standards were adopted by the ARB in November, 1998. These standards would become effective from the year 2004 until 2010.

Under the LEV II regulation, the light-duty truck and medium-duty vehicle categories of below 8500 lbs gross weight are reclassified and will have to meet passenger car requirements, as shown in Table A4.9. As a result, most pick-up trucks and sport utility vehicles will be required to meet the passenger car emission standards. The reclassification will be phased-in by the year 2007.

Medium duty vehicles above 8500 lbs gross weight (old MDV4 and MDV5) will still certify to the medium-duty vehicle standard (Table A4.10).

Table A4.8 California emission standards for medium-duty vehicles, FTP 75, g/mi

Category	50,000 miles/5 years					120,000 miles/11 years				
	NMOG ^a	CO	NOx	PM	HCHO	NMOG ^a	CO	NOx	PM	HCHO
MDV1, 0-3750 lbs										
Tier 1	0.25	3.4	0.4	-	-	0.36	5	0.55	0.08	-
LEV	0.125	3.4	0.4	-	0.015	0.18	5	0.6	0.08	0.022
ULEV	0.075	1.7	0.2	-	0.008	0.107	2.5	0.3	0.04	0.012
MDV2, 3751-5750 lbs										
Tier 1	0.32	4.4	0.7	-	-	0.46	6.4	0.98	0.1	-
LEV	0.16	4.4	0.4	-	0.018	0.23	6.4	0.6	0.1	0.027
ULEV	0.1	4.4	0.4	-	0.009	0.143	6.4	0.6	0.05	0.013
SULEV	0.05	2.2	0.2	-	0.004	0.072	3.2	0.3	0.05	0.006
MDV3, 5751-8500 lbs										
Tier 1	0.39	5	1.1	-	-	0.56	7.3	1.53	0.12	-
LEV	0.195	5	0.6	-	0.022	0.28	7.3	0.9	0.12	0.032
ULEV	0.117	5	0.6	-	0.011	0.167	7.3	0.9	0.06	0.016
SULEV	0.059	2.5	0.3	-	0.006	0.084	3.7	0.45	0.06	0.008
MDV4, 8501-10,000 lbs										
Tier 1	0.46	5.5	1.3	-	0.028	0.66	8.1	1.81	0.12	-
LEV	0.23	5.5	0.7	-	0.028	0.33	8.1	1	0.12	0.04
ULEV	0.138	5.5	0.7	-	0.014	0.197	8.1	1	0.06	0.021
SULEV	0.069	2.8	0.35	-	0.007	0.1	4.1	0.5	0.06	0.01
MDV5, 10,001-14,000 lbs										
Tier 1	0.6	7	2	-	-	0.86	10.3	2.77	0.12	-
LEV	0.3	7	1	-	0.036	0.43	10.3	1.5	0.12	0.052
ULEV	0.18	7	1	-	0.018	0.257	10.3	1.5	0.06	0.026
SULEV	0.09	3.5	0.5	-	0.009	0.13	5.2	0.7	0.06	0.013

^aNMHC for all Tier 1 standards

MDV - medium-duty vehicle (the maximum GVWR from 8,500 to 14,000 lbs). The MDV category is divided into five classes, MDV1 - MDV5, based on vehicle test weight. The definition of "test weight" in California is identical to the Federal ALVW.

NMOG - non-methane organic gases

HCHO - formaldehyde

Source <http://www.dieselnet.com/standards/us/light.html> as on 2 September 2002

Table A4.9 California LEV II emission standards, passenger cars and LDVs < 8500 lbs, g/mi

Category	50,000 miles/5 years					120,000 miles/11 years				
	NMOG	CO	NOx	PM	HCHO	NMOG	CO	NOx	PM	HCHO
LEV	0.075	3.4	0.05	-	0.015	0.09	4.2	0.07	0.01	0.018
ULEV	0.04	1.7	0.05	-	0.008	0.055	2.1	0.07	0.01	0.011
SULEV	-	-	-	-	-	0.01	1	0.02	0.01	0.004

Source: <http://www.dieselnet.com/standards/us/light.html> as on 2 September 2002

Table A4.10 California LEV II emission standards, medium duty vehicles, durability 120,000 miles, g/mi

Weight (GVWR), lbs	Category	NMOG	CO	NOx	P.M	HCHO
8,500 - 10,000	LEV	0.195	6.4	0.2	0.12	0.032
	ULEV	0.143	6.4	0.2	0.06	0.016
	SULEV	0.1	3.2	0.1	0.06	0.008
10,001 - 14,000	LEV	0.23	7.3	0.4	0.12	0.04
	ULEV	0.167	7.3	0.4	0.06	0.021
	SULEV	0.117	3.7	0.2	0.06	0.01

Source: <http://www.dieselnit.com/standards/us/light.html> as on 2 September 2002

Under the LEV II standard, NO_x and PM standards for all emission categories are significantly tightened. The same standards apply to both petrol and diesel vehicles (under revisions adopted on 15 November 2001 petrol vehicles are no longer exempted from the PM standard). Light-duty LEVs and ULEVs will certify to a 0.05 g/mi (0.031 g/km) NO_x standard, to be phased-in starting with the 2004 model year. A full useful life PM standard of 0.010 g/mi (0.006 g/km) is introduced for light-duty diesel vehicles and trucks less than 8500 lbs gross weight certifying to LEV, ULEV, and SULEV standards. The TLEV emission category has been eliminated in the final regulatory text.

Heavy-duty vehicles

Emission limits for heavy-duty engines were originally set in 1970 and, in the 1977 Clean Air Act, stringent reductions in HC and CO emissions were proposed to take effect in 1981. However, these standards were deferred until technology was available and were finally implemented in 1987, requiring catalysts on heavy-duty petrol engines. Further reductions in NO_x and diesel particulate limits, implemented from 1990 to 1995, required 3-way catalysts for heavy duty petrol engines and radical changes in diesel engine technology.

Heavy-duty vehicles are defined as vehicles of GVWR (gross vehicle weight rating) of above 8,500 lbs in the federal jurisdiction and above 14,000 lbs in California (model year 1995 and later). Diesel engines used in heavy-duty vehicles are further divided into service classes by GVWR, as follows.

- Light heavy-duty diesel engines: 8,500 < LHDDE < 19,500 (14,000 < LHDDE < 19,500 in California, 1995+)
- Medium heavy-duty diesel engines: 19,500 ≤ MHDDE ≤ 33,000
- Heavy heavy-duty diesel engines (including urban bus): HHDDE > 33,000

The US standards apply over the 'useful life' of the vehicle. The useful life is defined for each category of vehicle over the distance travelled or by the age.

Model year 1988-2003

Model year 1988-2003 US federal (EPA) and 1987-2003 California (ARB) emission standards for heavy-duty diesel truck and bus engines are summarized in Tables A4.11 and A4.12. The sulphur content in the certification fuel was reduced to 500 ppm from 1994 onwards.

Table A4.11 EPA emission standards for heavy-duty diesel engines, g/bhp-hr

	HC	CO	NO _x	PM
<i>Heavy-duty diesel truck engines</i>				
1988	1.3	15.5	10.7	0.6
1990	1.3	15.5	6	0.6
1991	1.3	15.5	5	0.25
1994	1.3	15.5	5	0.1
1998	1.3	15.5	4	0.1
<i>Urban Bus Engines</i>				
1991	1.3	15.5	5	0.25
1993	1.3	15.5	5	0.1
1994	1.3	15.5	5	0.07
1996	1.3	15.5	5	0.05*
1998	1.3	15.5	4	0.05*

* - in-use PM standard 0.07

Source: <http://www.dieselnet.com/standards/us/hd.html> as on September 2, 02.

Table A4.12 California emission standards for heavy-duty diesel engines, g/bhp-hr

Year	NMHC	THC	CO	NO _x	PM
<i>Heavy-duty diesel truck engines</i>					
1987	-	1.3	15.5	6	0.6
1991	1.2	1.3	15.5	5	0.25
1994	1.2	1.3	15.5	5	0.1
<i>Urban bus engines</i>					
1991	1.2	1.3	15.5	5	0.1
1994	1.2	1.3	15.5	5	0.07
1996	1.2	1.3	15.5	4	0.05

Source: <http://www.dieselnet.com/standards/us/hd.html> as on 2 September 2002.

Model year 2004 and later

In October 1997, EPA adopted new emission standards for model year 2004 and later heavy-duty diesel truck and bus engines. These standards are as per the provisions of the Statement of Principles (SOP) signed in 1995 by the EPA, California ARB, and the manufacturers of heavy-duty diesel engines. The goal was to reduce NO_x emissions from highway heavy-duty engines to levels of approximately 2.0 g/bhp-hr beginning in 2004. Manufacturers have the flexibility to certify their engines to one of the two options shown in Table A4.13.

Table A4.13 EPA emission standards for MY 2004 and later HD diesel engines, g/bhp-hr

Option	NMHC + NO _x	NMHC
1	2.4	n/a
2	2.5	0.5

Source <http://www.dieselnets.com/standards/us/hd.html> as on 2 September 2002.

In October 1998, a Consent Decree was designed between the EPA, Department of Justice, California ARB and engine manufacturers over the issue of high NO_x emissions from heavy duty diesel engines. The provisions of this Decree include civil penalties for engine manufacturers and requirements to allocate funds for pollution research, upgrading existing engines to lower NO_x emissions and meeting the 2004 emission standards by October 2002.

Model year 2007 and later

On 21 December 2000, the EPA signed emission standards for model year 2007 and later heavy-duty highway engines (the California ARB adopted virtually identical 2007 heavy-duty engine standards in October 2001). The rule includes two components: (1) emission standards, and (2) diesel fuel regulation.

The first component of the regulation introduces new, very stringent emission standards, as follows:

- PM 0.01 g/bhp-hr (0.013 g/kw-hr)
- NO_x 0.20 g/bhp-hr (0.27 g/kw-hr)
- NMHC 0.14 g/bhp-hr (0.19 g/kw-hr)

The PM emission standard will take full effect in the 2007 heavy-duty engine model year. The NO_x and NMHC standards will be phased-in for diesel engines between 2007 and 2010. The phase-in would be on a percent-of-sales basis: 50% from 2007 to 2009 and 100% in 2010 (petrol engines are subject to these standards based on a phase-in requiring 50% compliance in 2008 and 100% compliance in 2009).

The diesel fuel regulation limits the sulphur content in on-highway diesel fuel to 15 ppm with effect from 1 June 2006. The refiners can take advantage of a temporary compliance option that will allow them to continue producing 500 ppm fuel in 20% of the volume of diesel fuel they produce until 31 December 2009. In addition, refiners can participate in an averaging, banking and trading programme with other refiners in their geographic area.

Annex 4.3 Emission standards in Japan

Table A4.14 Motor vehicle exhaust emission standards in Japan

Vehicle type	Inertia weight	Units	NOx	NMHC	CO	PM
Diesel passenger vehicle	EIW<1250 kg and 1250 kg	g/km	0.14	0.024	0.63	0.013
	EIW>1250 kg	g/km	0.15	0.024	0.63	0.014
Diesel trucks and buses	GVW<1750 kg and 1750 kg	g/km	0.14	0.024	0.63	0.013
	1750 kg < GVW < 3500 kg and 3500 kg	g/km	0.25	0.024	0.63	0.015
	3500 kg < GVM	g/kWh	2.0	0.17	2.22	0.027
Petrol passenger vehicle	All	g/km	0.05	0.05	1.15	NA
Petrol light duty vehicles	All	g/km	0.05	0.05	1.02	NA
Petrol trucks and buses	GVW<1750 kg and 1750 kg	g/km	0.05	0.05	1.15	NA
	1750 kg <GVW < 3500 kg and 3500 kg	g/km	0.07	0.05	2.55	NA
	3500 kg < GVW	g/kWh	0.7	0.23	16.0	NA

EIW= Equivalent inertia weight, GVW = Gross vehicle weight

Source: Carlines April 2002, <http://www.env.go.jp/en/jeq/v007-02.html> as on 3 September 20 02.

Table A4.15 Vehicle exhaust emission standards in Japan till 1999

Category			Mode	Components	Regulation		Remarks				
					Enforcement year	Standard value					
Petrol and LPG motor vehicles	Passenger cars	4-cycled and 2-cycled	10-15M (g/km)	CO	1975	2.70 (2.10)	Currently 2-cycled passenger cars are not manufactured.				
				HC	1975	0.39 (0.25)					
				NOx	1978	0.48 (0.25)					
		11M (g/test)		CO	1975	85.0 (60.0)					
				HC	1975	9.50 (7.00)					
				NOx	1978	6.00 (4.40)					
				Trucks and buses	4-cycled mini- sized motor vehicles	10-15M (g/km)		CO	1998	8.42 (6.50)	Currently these vehicles are not manufactured.
								HC	1998	0.39 (0.25)	
								NOx	1998	0.48 (0.25)	
	11M (g/test)		CO		1998	104 (76)					
			HC		1998	9.50 (7.00)					
			NOx		1998	6.00 (4.40)					
	2-cycled mini- sized motor vehicles	10-15M (g/km)	CO		1975	17.0 (13.0)					
			HC		1975	15.0 (12.0)					
			NOx		1975	0.50 (0.30)					
	Light-duty vehicles (GVW≤1.7t)	11M (g/test)		CO	1975	130 (100)					
				HC	1975	70.0 (50.0)					
				NOx	1975	4.00 (2.50)					
		10-15M (g/km)		CO	1988	2.70 (2.10)					
				HC	1988	0.39 (0.25)					
				NOx	1988	0.48 (0.25)					
		11M (g/test)		CO	1988	85.0 (60.0)					
				HC	1988	9.50 (7.00)					
				NOx	1988	6.00 (4.40)					
	Medium-duty vehicles (1.7t < GVW ≤2.5t)	10-15M (g/km)		CO	1998	8.42 (6.50)					
				HC	1998	0.39 (0.25)					
				NOx	1994	0.63 (0.40)					
		11M (g/test)		CO	1998	104 (76)					
				HC	1998	9.50 (7.00)					
				NOx	1994	6.60 (5.00)					
	Heavy-duty	G13M		CO	1998	68.0 (51.0)	LPG-fueled 105(76)				

Category		Mode	Components	Regulation		Remarks
				Enforcement year	Standard value	
Diesel motor Passenger vehicles	cars	vehicles (2.5t < GVW)	HC	1998	2.29 (1.80)	
			NOx	1995	5.90 (4.50)	
		10-15M (g/km)	CO	1986	2.70 (2.10)	
			HC	1986	0.62 (0.40)	
			NOx Small	1997	0.55 (0.40)	
			NOx Medium	1998	0.55 (0.40)	
	Trucks and buses	Light-duty vehicles (GVW ≤ 1.7t)	PM	1997, 1998	0.14 (0.08)	Small 1997, Medium 1998
			CO	1988	2.70 (2.10)	
			HC	1988	0.62 (0.40)	
			NOx	1997	0.55 (0.40)	
			PM	1997	0.14 (0.08)	
		Medium-duty vehicles (1.7t < GVW ≤ 2.5t)	CO	1993	2.70 (2.10)	
			HC	1993	0.62 (0.40)	
			NOx	1997, 1998	0.97 (0.70)	MTM 1997
		Heavy-duty vehicles (2.5t ≤ GVW)	PM	1997, 1998	0.18 (0.09)	ATM 1998
			CO	1994	9.20 (7.40)	
			HC	1994	3.80 (2.90)	
			NOx DI	1997,	5.80 (4.50)	GVW ≤ 3.5t, 1997
			NOx IDI	1998, 1999		3.5t < GVW ≤ 12t, 1998
			PM	1997, 1998, 1999	0.49 (0.25)	12t < GVW, 1999
Two-wheeled motor vehicles	4-cycled	Two-wheeled motor vehicles (g/km)	CO	1998, 1999	20.0 (13.0)	*
			HC	1998, 1999	2.93 (2.00)	
			NOx	1998, 1999	0.51 (0.30)	
	2-cycled	Two-wheeled motor vehicles (g/km)	CO	1998, 1999	14.4 (8.00)	
			HC	1998, 1999	5.26 (3.00)	
			NOx	1998, 1999	0.14 (0.10)	

Notes:

1. Standard value "2.70(2.10)" means that the maximum permissible limit per unit is 2.70 and the average permissible limit for each category of motor vehicle is 2.10
2. 10-15M means 10-15-mode cycle which reflects an average driving pattern in cities. "11M" means 11-mode cycle which reflects a driving pattern of vehicles which make a cold start to drive to cities from outside cities
3. As for diesel-powered passenger cars, "small" vehicle means a vehicle with equivalent initial weight (EIW) of 1.25t or less, "medium" vehicle means a vehicle with EIW of more than 1.25t
4. "MTM" and "ATM" stand for manual transmission and automatic transmission respectively
5. "DI" and "IDI" stand for direct injection and indirect injection respectively.

Source: <http://www.env.go.jp/en/jeq/v007-02.html> as on 3 September 2002.

Annex 4.4 Indian emission standards

Table A4.16. Mass emission norms for petrol vehicles

Three - wheelers (g/km)				
Year	CO	HC	HC + Nox	
1991	12 - 30	8 - 12	-	
1996	6.75	-	5.40	
2000	4.00	-	2.00	
Two - wheelers (g/km)				
Year	CO	HC	HC + Nox	
1991	12 - 30	8 - 12	-	
1996	4.50	-	3.60	
2000	2.00	-	2.00	
Car (g/km)				
Year	CO	HC	HC + Nox	
1991	14.3 - 27.1	2.0 - 2.9		
1996	8.68 - 12.4	..	3.00 - 4.36	
1998*	4.34 - 6.20	..	1.50 - 2.18	
2000	2.72	..	0.97	
B.S II	2.2	..	0.5	
B.S II	2.2 - 5.0	..	0.5 - 0.7	

* For vehicles fitted with catalytic converter upto 6 seaters and GVW upto 2.5 tonnes more than 6 seaters & GVW upto 3.5 tonnes

Table A4.16. Emission norms for diesel vehicles

Diesel Vehicles (GVW Upto 3.5 tonnes)				
(g/ kWh)	Engine dynamometer			
Year	CO	HC	Nox	PM
1992	14	3.5	18	
1996	11.20	2.40	14.4	
2000	4.5	1.1	8.0	0.36/ 0.61 #
B S II	4.0	1.1	7.0	0.15

or

(g/km)	Chassis dynamometer			
Year	CO	HC	HC + Nox	PM
1992	17.3 - 32.6	2.7 - 3.7	.	.
1996	5.0 - 9.0	.	2.0 - 4.0	.
2000	2.72 - 6.90	.	0.97 - 1.70	0.14 - 0.25
B.S II	1.0 - 1.5	.	0.7 - 1.2	0.08 - 0.17

Light duty vehicles

Cars				
(g/km)	Chassis dynamometer			
B.S. II	1.0	.	0.7	0.08
				upto 6 seaters and GVW upto 2.5 t
B.S. II	1.0 - 1.5	.	0.7 - 1.2	0.08 - 0.17
				More than 6 seaters and GVW upto 3.5 t

Diesel Vehicles (GVW > 3.5 Tonnes)

(g/ kwh) Engine dynamometer

Year	CO	HC	No _x	PM
1992	17.3 - 32.6	2.7 - 3.7	.	.
1996	11.20	2.40	14.4	.
2000	4.5	1.1	8.0	0.36/0.36 #
B.S II	4.0	1.1	7.0	0.15

For engines with power exceeding 85 kW/ For engines with power upto 85 kW

Source: <http://www.siamindia.com/> as on 1 August 2002

Annex 5.1 Diesel quality

The improvements in diesel quality include:

- (a) Increase of Cetane number for better engine performance,
- (b) Control of poly aromatic hydrocarbon (PAH) content, decreasing the fuel density and 95% point, and reducing sulphur content in the fuel for emissions control, and,
- (c) Addressing the following fuel properties: lubricity, Cold Filter Plugging Point and Cloud Point.

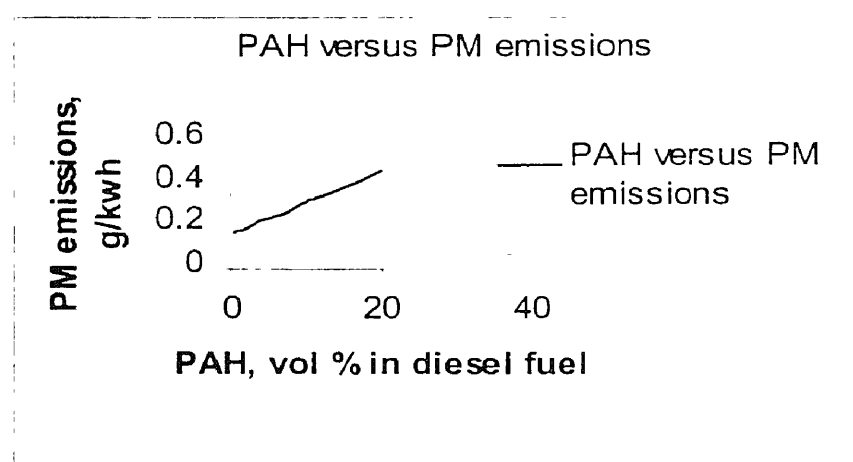
Cetane Number

The improvements in quality of diesel have made diesel lighter, thereby making it more paraffinic in molecular composition, as, for the same carbon number, paraffins are lighter species of hydrocarbons. This results in the increase of Cetane Number whose minimum limit has also been progressively increased. Cetane Number is a very important combustion property and has a direct bearing on the efficiency of the engine. It is also important to note that increase in Cetane Number either by changing the molecular composition of the diesel fuel or by the addition of a cetane improver additive are at a cost which would vary significantly between different refinery sources. The cost of improving Cetane Number by 3 numbers from Euro II to Euro III level using a cetane improving additive will depend upon the type of additive that is used. Refinery processing to increase Cetane Number would also decrease the aromatics in the diesel fuel. The most common cetane improver used is 2-ethyl hexyl nitrate. The cost of improving Cetane Number from 48 Cetane Number to 51 Cetane Number would be only about one dollar per ton of diesel, which makes it economical to add a CI additive when compared to the hydro processing route to increase Cetane Number (Shell Global Solutions, 1999).

Polycyclic Aromatic Hydrocarbons and T95

This is the most important source of particulate emissions from diesel engines, particularly in the older engines (Lee, 1998). It also contributes to NO_x emissions due to higher flame temperatures associated with aromatic compounds. These are generated during some secondary refinery processes and would require significant treatment to saturate aromatics to paraffinic components. The T95 point represents the percentage of heavier and bigger molecules in diesel fuel. Most of the species of the PAH are in the upper limit of the T95 and reduction in the limit for T95 would also result in a decrease of the PAH content in diesel. This has also been reduced significantly in order to

reduce the percentage of heavier and bigger molecules in diesel (Nakakita, 1998; Tanaka, 1998). These changes have led to the diesel becoming lighter (reduced density) which also helps in better emissions performance. A study points out that even though the aromatics in diesel do not affect the combustion characteristics, they do have an effect on the particulate and nitrogen oxide emissions (Kidoguchi, 2000). As already indicated above, these changes are highly cost-intensive in terms of capital involved and, more importantly, operating costs which will result in an increase in the cost of diesel. The effect of PAH on particulate matter is illustrated in Figure A5.1 (Tanaka 1998), which shows that there is a significant impact of PAH content in diesel on PM emissions from diesel engines.



FigureA5.1 Effect of PAH content in diesel on PM emissions

phur

This component in diesel fuel contributes to particulate emissions and also reduces the activity of the advanced emissions control catalysts. The effect of sulphur content in diesel on particulate emissions from a diesel engine is schematically represented in Figure A5.2 (Stuart Neill, 2000). The effect of S in PM emissions from diesel engines is not very significant except for increased sulphate emissions. The reduction of sulphur in diesel would, again just like the increase in Cetane Number, be a cost-intensive process. There are a few technologies being developed that would significantly lower the cost of reducing sulphur in diesel. A number of developed countries in critical regions have introduced standards requiring less than 50ppm levels of sulphur content to allow advanced emission control devices for the reduction of PM emissions.

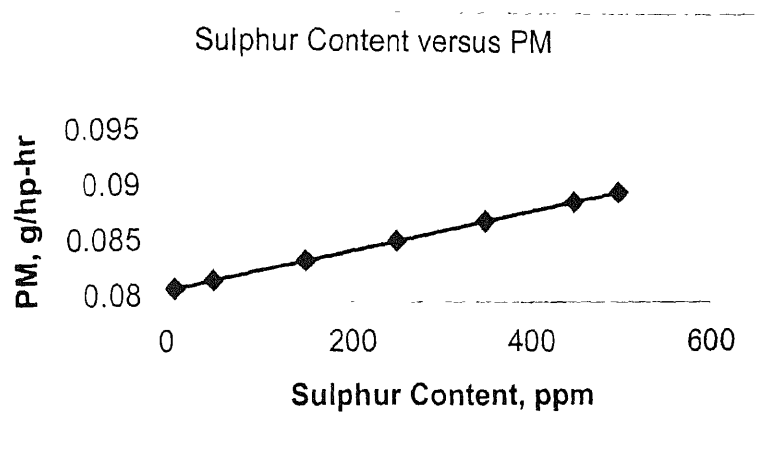


Figure A5.2 Effect of S content in diesel on particulate matter emissions

Table A5.1 summarizes the effect of diesel fuel properties on heavy-duty diesel emissions (Lee, 1998).

Table A5.1 Summarized influence of fuel properties on heavy-duty diesel emissions

Fuel Modification	HC	CO	NOx	PM
Reduce sulphur	No effect	No effect	No effect	Reduces (small effect) ^a
Increase Cetane	No effect ^b	No effect ^c	Small effect	No effect
Reduce PAH	Reduces (small effect)	No effect	Reduces (small effect)	Reduces (large effect)
Reduce Density	Increases (large effect)	Increases (small effect)	Reduces (small effect)	Reduces (large effect) ^d

^aVery significant when sulphur reduces from 0.3 % to 0.05 % but not significant when S reduces from 0.05 % to lower levels.

^bSignificant for older engines

^cSignificant for older engines

^dSignificant for older engines and not significant for newer engines

Of all emission related properties of diesel that are important in reducing emissions, post combustion emission control devices are the primary driver. All other fuel properties will have only minor or secondary effects on the tailpipe emissions in newer engines. The properties of diesel fuel will nevertheless be very important for older engines where the latest emission control devices cannot be fitted.

Lubricity

With the continuous reduction in sulphur and aromatic levels in diesel, the lubricity of diesel has also reduced significantly. This will have to be compensated by a lubricity additive.

Annex 5.2 International experiences on ULSD

Sweden

It was the first country to have introduced ultra-low sulphur diesel (ULSD). Its specifications for ULSD (city diesel) are among the toughest in the world. ULSD was introduced by the Swedish Government with Environmental Classification, E1, (less than 10 ppm S) and E2 (below 50 ppm) on 1 January 1991. The E2 grade was discontinued in 1996. The E1 product was given a very high tax incentive making it so attractive that some oil companies switched over completely to manufacturing the E1 grade. The tax differential between E1 and E3 (350 ppm max) in 2000, was 19 US cents per gallon. As a result of this high tax incentive, E1 has a market share of almost 100%.

Denmark

Tax incentives of 0.18 DKK/litre for ULSD (with maximum 50 ppm sulphur diesel) were introduced from 30 June 1999. The result was a nearly 100% penetration of 50 ppm sulphur diesel in the Danish market from July 1999.

United Kingdom

In the UK a differential rate of duty was introduced for ULSD with 50 ppm sulphur. Initially set at 1 pence per litre, this differential was increased in the March 1999 Budget to 2 pence per litre, and up to 3 pence per litre in the March 2000 budget. The introduction of this duty differential has had a significant effect on moving consumers over to ULSD (www.platt.com). As a result of these initiatives, all the buses in London now operate on ULSD.

Germany

The government will offer tax breaks for sulphur-free petrol and diesel from 2003. The tax break of Euro 0.015 (0.014 cts) per litre for fuels with no more than 10 parts per million sulphur will be offered from 1 Jan 2003 until 1 Dec 2005. The incentives are expected to accelerate the EU-wide shift towards very low sulphur motor fuels. Germany already gives differential tax incentives to encourage transition of its domestic market to fuels containing less than 50 parts per million (ppm) of sulphur.

As per the EU directives, nearly all the 100 European refineries will have to produce 50 ppm S diesel by 2005 and 10 ppm S diesel by 2008 or 2009. All the EU member countries (Austria, Belgium, Denmark, Finland, Greece, Italy, Luxemburg, Ireland, Netherlands, Portugal, Spain, Sweden, UK, Germany, France) have either moved or are moving to ULSD with important consequences in terms of availability of this fuel for export to other markets.

USA

In the US, the Environmental Protection Agency (EPA) issued final rules late in December 2000 to cut sulphur levels by 97% from 500 ppm to 15 ppm. The new standard will be effective for 75%–80% of the total diesel fuel supply by June 2006. The remaining suppliers have until late 2009 to comply. Refiners will receive credits, which they will be able to buy and sell, for meeting the standards early.

Many city transit authorities in US are extensively using ULSD in combination with appropriate after-treatment or emission control devices to reduce PM and NO_x emissions.

Japan

The Japanese government has adopted a requirement that all diesel fuel must be under 50 ppm by 2005. The oil industry has announced that they will do even better and has committed that all fuel sold in the country by 2003 will be under 50 ppm. Some fuels having less than 50 ppm sulphur are already being sold to certain bus fleets in Tokyo. The government has announced financial support to public transportation such as city buses, which are introducing effective retrofit systems on a voluntary basis. The total subsidy in 2001 was 200 million yen (1.6 million dollars).

Hong Kong

The Hong Kong government adopted a tax incentive scheme in 2000, of a concessionary duty of 1.11 Hong Kong dollars litre, which made diesel fuel with less than 50 ppm sulphur, less expensive than diesel fuel with more than 50 ppm. A duty differential of the Hong Kong dollar 0.89 was been given to offset the higher price of ULSD. As a result, all diesel fuel now sold in Hong Kong is 50 ppm or less.

Annex 5.3 Petrol quality

Engine performance and Combustion-related

Octane Number is an important property, that affects the engine performance and the combustion in spark ignition engines. Both Research and Motor Octane Number (RON and MON) have been increased significantly in the Euro III standards over Euro II standards. This increase entails major changes to the components, which comprise the refinery petrol pool and also new components, which need to be added such as MTBE, ethanol, iso-octane (alkylates) to boost the Octane number. These components will also compensate for the decrease in Octane Number due to the reduction of aromatics in the petrol pool with the specifications reducing their maximum allowable limit.

Aromatics and olefins

Aromatics and olefins contribute to hydrocarbon and NO_x emissions significantly and also form deposits in the inlet valves and combustion chambers. These are being reduced to lower levels in petrol but not as significantly as in case of US regulations for petrol. Reducing olefins and aromatics in petrol as already mentioned above would need the addition of new components to petrol such as MTBE, ethanol, iso-octane (also called alkylates which are very important and emerging petrol blend components) etc. This is a cost-intensive quality change and the cost would be significantly high for refineries with only a catalytic reformer, which produces aromatics-based petrol.

The options available to decrease aromatics and olefins in petrol without causing any octane loss are given below:

- Blending of ethers such as MTBE, TAME
- Blending of ethanol
- Blending of alkylates (iso-octane)

Sulphur

The sulphur in petrol deactivates the three-way catalyst that is fitted to reduce the HC, CO and NO_x emissions and causes an increase in emissions as the catalyst gets deactivated. This has been reduced in future regulations, to less than 50ppm. The important point to be noted in this regard is that the processes to reduce sulphur could lead to reduction in Octane number also and the selection of refinery processes to reduce sulphur without octane loss is a challenge.

Vapour pressure

The volatility of petrol has been under significant scrutiny to address the issue of evaporative emissions. This is not an issue with diesel-powered vehicles. To address this issue, the European and US regulations have different summer and winter norms for Reid Vapour Pressure and Vapour Lock Index. Though there are different VLI norms in India for summer and winter, the issue of RVP increase of petrol with ethanol blended to the extent of 5 % has not been addressed. Blending of ethanol in petrol to the extent of 5 % has been mandated from 1 January 2003 in the major sugar growing states. This is dealt with later. The effect of petrol quality on non-methane hydrocarbon emissions and NO_x emissions is illustrated in the following two Figures A5.3 and A5.4^{a,b} (Lester Wyborny, 2000).

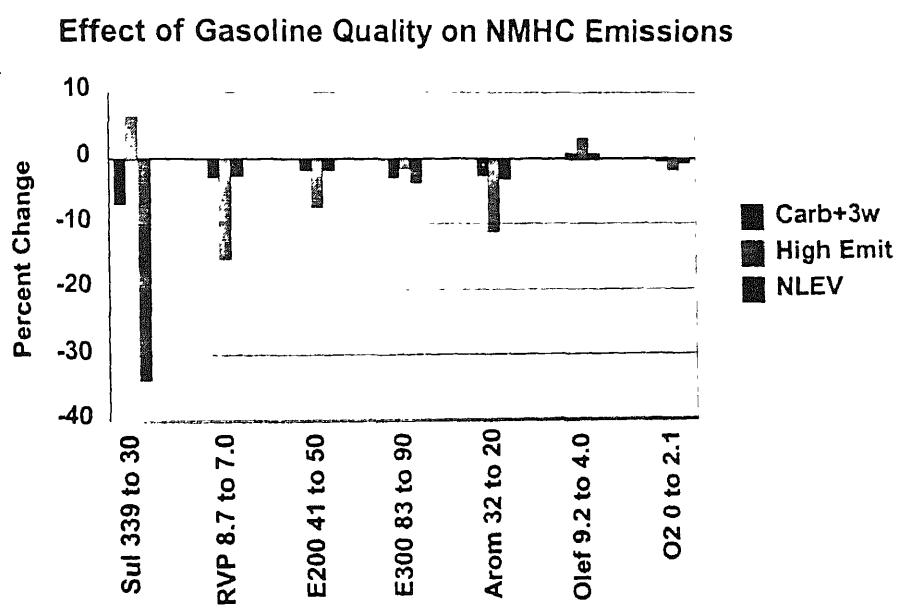


Figure A5.3 Effect of petrol quality on NMHC emissions

^a CARB – CARB grade petrol and emission norms, High emit is high emission vehicle, NLEV – National low emitting vehicle programme.

^b RVP in psi, olefins and aromatics in vol % and oxygen in wt %.

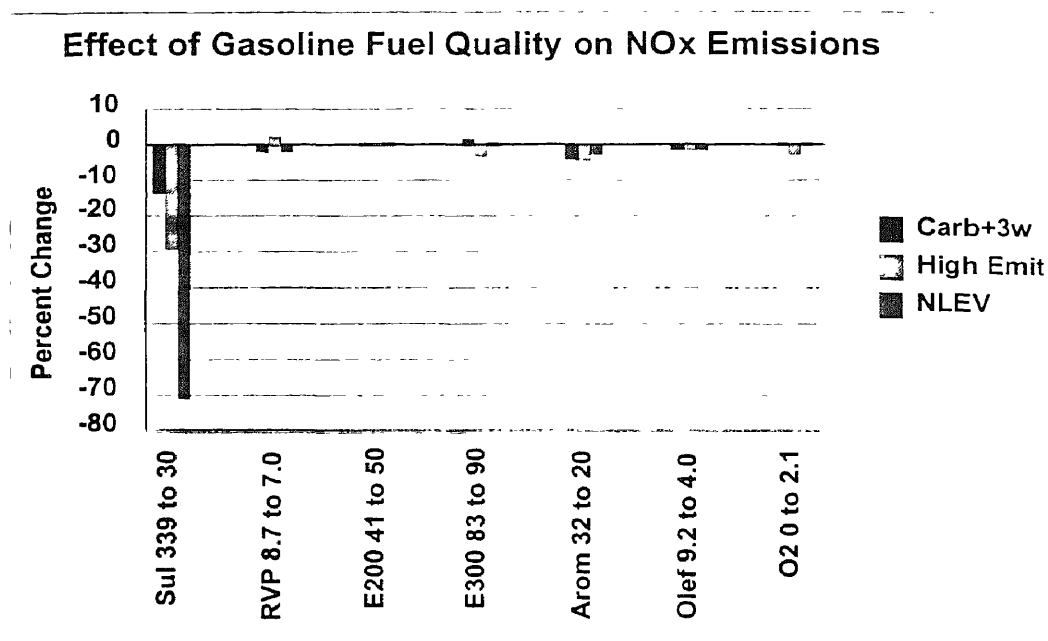


Figure A5.4 Effect of petrol quality on NO_x emissions

From Figures A5.3 and A5.4 it is clear that for the newer vehicles, sulphur is the most important quality parameter, that determines the emissions from low-emitting vehicles. For the high-emitting vehicles (older vehicles), other quality parameters also affect the emissions from petrol engines.

Petrol quality improvements have been more significant from the emissions reduction viewpoint in the US when compared to other countries in Europe. The Clean Air Act of 1992 mandated certain changes such as the introduction of a minimum oxygen content in petrol with a focus on the following issues:

- Ground level ozone reduction which is caused by the reaction between the reactive hydrocarbons and NO_x.
- Reduction in toxic air pollutants (TAP) such as 1, 3 butadiene, benzene, formaldehyde, etc.
- Carbon monoxide reduction.

In the US the approach is that the petrol produced by a refiner should result in reductions in emissions when compared to the 1990 baseline. The reduction has certain minimum limits depending upon the region and phase of reformulated gasoline (or petrol) implemented in that region. There were two phases of 'reformulated gasoline' which were essentially targeting reductions in certain percentages of the above mentioned pollutants. The emission reduction

limits from the 1990 baseline emissions under different phases for summer season are given below in Table A5.2.

Table A5.2 Reformulated petrol norms

Property	Phase 1	Phase 2
Oxygen wt % in petrol	2.1 min	2.1 min
Toxic air pollutants, % reduction	18.5	21.5
Volatile organic compounds, % reduction	20.8	29.0
Nitrogen oxides, % reduction	1.4	6.8

Annex 5.4 Cost of fuel quality upgradation

The Mashelkar Committee analysed the additional cost for different Indian refineries for producing Euro II and Euro III diesel (MoPNG 2002). These additional costs are listed for important refineries in Table A5.3.

Table A5.3 Cost differential between current and future diesel

Refinery	Important marketing location **	Euro I to Euro II (Rs/litre)	Euro I to Euro III (Rs/litre)
IOC Mathura	Delhi	1.23	1.41
IOC Gujarat	Baroda, Ahmedabad	0.84	1.03
RPL Jamnagar	Delhi, Jaipur	0.25	0.90
CPCL Chennai	Chennai, Bangalore	1.30	1.60
HPCL Mumbai	Mumbai, Pune	1.4	2.0
IOC Haldia	Kolkata	1.16	1.24

** All data except important marketing location taken from the Mashelkar Committee Report (MoPNG 2002).

The marketing locations are listed considering their distance from the refinery and the availability of pipeline infrastructure.

The total investment required to achieve Euro III fuel standards in India is 350 billion rupees in two stages, first to Euro II and then to Euro III. It is to be noted that Indian refineries still do not have any estimates of the investment/cost that would be incurred for producing Euro IV fuels (diesel and petrol).

Table A5.3 shows clearly that the older refineries incur higher fixed and operating costs for the production of these upgraded fuels.

A CONCAWE study in Europe conducted to evaluate the cost implications for refineries with different configurations has summarized the additional cost

implications for producing Euro IV diesel when compared to Euro III diesel as given in Table A5.4 (CONCAWE, 1999). The costs indicated are for different levels of S in diesel and are the average for European refineries having different configurations. These values will be relevant in the Indian scenario also because of the general similarity of the configuration of most Indian and European refineries. There are some refineries in India in the north-east in which production of the advanced grades of diesel will not be economically feasible and will require significant investments.

Table A5.4 Incremental cost in upgrading from Euro III to Euro IV

Level	Incremental cost Rs/litre
Euro III to Euro IV (Standard Specs)	0.30
Euro IV (50ppm S) to Euro IV (10ppm S)	0.21
Euro III to Euro IV (10ppm S)	0.51
Euro III to Euro IV (55 Cetane Number)	0.64

Source: ConcaWE 1999

These incremental costs would be incurred over and above the costs indicated for upgradation to Euro III level. This makes the cost of Euro IV diesel approximately 2.00 to 2.50 rupees per litre more than the price of the current grade of diesel sold in metros. These incremental prices can be influenced significantly by the following factors:

- 1 Incentives provided for investments made in achieving these fuel quality standards.
- 2 Competition in the sector and pricing strategies followed which might ensure that all of this incremental cost is not passed on to the consumer in order to be competitive.
- 3 Competition in terms of pricing and market share from equivalent alternative fuels, which would directly affect the sales of conventional fuels.

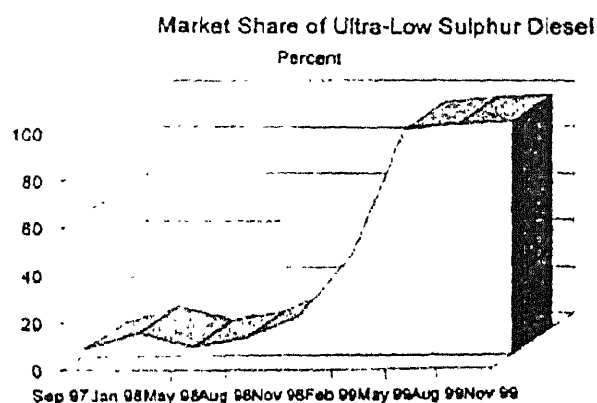
In this context it is also important to note that the cost to the consumer of the better quality fuel could be significantly lowered by the following incentives:

- In the form of accelerated depreciation and waiving of customs duty on capital goods imported for product quality up-gradation.
- Having a differential taxation regime between the same fuels but meeting different standards so that the cleaner fuel is taxed less than the current grade of fuel.

The price of diesel in the current deregulated market scenario at a particular location would be based on the actual cost of the product, which would depend primarily on the following factors.

- Location—inland or coastal location
- Source of diesel – Refinery source that will include the additional cost for production of the upgraded quality of diesel. The areas which would depend on the north-eastern refineries will have to pay a higher price than the metropolitan cities.
- Transport mode from source to destination – pipeline/rail/road
- Local sales tax levels – Significant variation between different states, which creates many distortions in prices between different regions.
- Marketing margins – this will be the major component of the price of the fuel, which vary will with competition in the marketing sector.

In UK, duty exemptions to refineries encouraged them to start producing Euro IV grade diesel by 2000 in place of the mandated deadline of 2005. The market share of ULSD (less than 50ppm S diesel) increased with duty exemptions announced by the UK government. Figure A5.5 shows that when the duty exemption was increased from one pence/litre to three pence/litre, the market share of ULSD increased to almost 100%. Similar exemptions were given by many EU member countries such as Germany, Sweden etc. in order to encourage refineries to upgrade their facilities earlier than the mandated deadlines. The policies framed so far in the Indian context do not provide any such incentives to either the refineries or automobile companies.



Source. HM Customs and Excise, *Using the tax system to encourage cleaner fuels: The experience of Ultra-Low Sulphur Diesel*, November 2000

Figure A5.5 Market Penetration of ULSD with fiscal incentives in UK (Please check and add)

Annex 5.5 International experience with LPG heavy-duty engines

LPG is more common in smaller vehicles, but comparatively less so in full-sized transit buses in contrast to the trend with CNG buses. Engine technology for LPG vehicles is very similar to that for natural gas vehicles, with the exception that LPG is seldom used in dual-fuel diesel applications, due to its poorer knock resistance. There are some studies internationally on the use of LPG for heavy-duty applications. Some studies have reported that LPG heavy-duty engines have durability problems with stoichiometric air-fuel ratios. Also, the emissions performance of lean-burn LPG engines was observed to be better than that of the stoichiometric engines (Goto 1999).

LPG or propane bus engines generally have lower emissions than their conventional diesel engines counterparts but even those are generally not as low as emission from natural gas engines. Experimental propane buses operated at a California-based transit agency underwent tests that indicated very low nitrogen oxide emissions (US General Accounting Office 1999).

In 1997, an LPG bus engine in British Columbia reported 'low emission values' (SYMPHER:MUELLER International, 1997). It had NO_x emissions of less than 3.7 g/bhp-hr and particulate emissions of 0.075 g/bhp-hr. According to a more recent report by the California Energy Commission, two commercially available dedicated LPG engines have been certified as meeting California's heavy-duty optional low-NO_x credit standards (see Table A5.5) (CEC 2001). Dedicated medium heavy-duty LPG engines of model year 2000 conformed to low NO_x standards.

Table A5.5. Certified emission results of LPG heavy-duty engines (g/bhp-hr)

Manufacturer	NO _x	PM
IMPCO	0.8	NA
Cummins ^a	2.3	0.01

^aEngine specifications of the Cummins B5.9 engine can be found in (Cummins Engine Company, Inc., 1998)

Like all gas vehicles, LPG buses too can benefit from the advantages of gaseous fuels, i.e. the near absence of sulphur and a low carbon-hydrogen ratio, which tends to cause relatively low CO₂ emissions. However, this latter advantage is mainly offset by the currently low energy efficiency of combustion. LPG buses are less fuel-efficient than diesel buses, and hence their driving range is somewhat lower than for comparable vehicles. As with CNG buses, LPG

engines, which are also spark-ignited, can be stoichiometric or lean burn, the latter being the more promising option.

The main experience with LPG exists with smaller buses rather than full sized ones. According to a report, the use of LPG as a fuel in transit bus fleets brings with it some concerns about safety (US General Accounting Office 1999). It should therefore be noted that the emissions values do not necessarily justify a choice in favour of LPG buses. The relevance of the relative emission savings must be carefully analysed in the light of the individual situation. Thus for instance, the total emission reductions achieved through a particle filter on a conventional diesel bus may be perfectly sufficient to alleviate a high PM level problem. Other factors, such as cost effectiveness, may then be decisive regarding the choice of system. The US General Accounting Office states that the use of propane as a fuel in transit bus fleets brings with it high operating and capital costs (US General Accounting Office 1999).

LPG buses have been used in Vienna, Austria, for 30 years and with about 500 LPG buses, the city is operating the world's largest bus fleet running on LPG. Field experience has revealed that LPG buses have achieved emission values that are below the standards defined in the concept of the Euro III regulation for diesel engines. According to the website on Vienna Climate Protection Programme: LPG-fuelled bus fleet, 'completely soot-free combustion ensures low-noise operation and a longer service life'. It is reported that the LPG bus fuel efficiency is however lower than with diesel buses, and the initial purchase price is 10%-15% higher for LPG buses (SYIPHER:MUELLER International, 1997). Maintenance costs are slightly higher and catalytic converters must be replaced every two years. Maintenance facilities must be modified to increase the ventilation. These additional costs are offset by far lower fuel prices and significant reduction in emissions.

While LPG is the most widely used alternative fuel worldwide, its use in heavy-duty vehicles such as transit buses is relatively limited. There is a strong competition from the natural gas industry in the heavy-duty sector. The main obstacles to the widespread use of LPG buses in developing country cities are likely to be the demand for additional training and knowledge about handling LPG, inspection and maintenance, higher costs compared to diesel buses and lower driving ranges. Further challenges come from competition with natural gas buses, as well as the development of advanced diesel buses equipped with particle filters and catalytic converters using low sulphur diesel fuel, which compete with gas buses as they, too, become cleaner.

Annex 5.6 LPG specifications

Of the hydrocarbons commonly included in LPG, propane has the best antiknock property compared to petrol. The antiknock property of other components in LPG is inferior to propane and petrol, which raises an important concern on the design parameters to be used for designing spark ignition LPG engines. For example, the common components of LPG, are propylene, butanes, and butenes. With propylene, butenes, and butadienes in LPG, there would be significant reactive hydrocarbon and NO_x emissions as they are olefinic components and have the same effect as olefins in petrol. In this context many countries have notified standards, which mandate the use of neat propane only. It is also important to note that propane will not offer any specific advantage as far as its higher octane number is concerned if the existing petrol engine design is just modified to use LPG. In Europe a minimum Motor Octane Number (MON) of 89 for LPG has been mandated in order to ensure satisfactory operation on LPG of engines designed for European premium leaded petrol having a MON of 87. The higher MON was mandated in order to be able for use in older engines also. In US LPG is mandated to be 'neat' propane. Table A5.6 gives the propane and propene content in LPG in different countries.

Table A5.6 Propane and propene content of LPG in different countries

Country	Vol % in LPG
Belgium	40 - 60
France	20 - 50
Germany	100
Netherlands	30 - 70
US	98 - 100

The auto LPG quality in India does not specify any minimum quantity of propane and is produced mainly in the refineries. LPG can be produced by many processes. It is a part of the crude oil and its percentage in crude oil varies but consists of propane and butane (both normal-butane and iso-butane, iso-butane has the higher octane number of the two). Significant quantities of LPG in India are produced from secondary refining processes such as fluidized catalytic cracking. LPG from these secondary-processing units would be very 'olefinic' (components like propylene, butenes and butadienes) due to the nature of these processes. A critical unregulated pollutant in the US is 1, 3-butadiene. The emissions of these are very high when LPG is used as a fuel. It is also to be noted that refineries have been opposing introduction of max 'olefins' content in LPG

fuel quality standard in view of the processes being used for production of LPG and the economic impact that it would have on the price. Additional facilities would have to be installed in order to convert these 'olefinic' LPG components to propane and butane alone. India is not self sufficient in LPG like it is in petroleum products like petrol and diesel where there is a surplus capacity in terms of refining capacity. This will give rise to the issue of the availability of LPG as an auto fuel. The Mashelkar Committee Report also points out a deficit in the LPG supply assuming a 10 % petrol demand substitution by auto LPG after two years and 25% after five years. The projected deficit is 0.8 MMT (metric million tonnes) in 2002–03, 2.75 MMT in 2004–05 and 5.88 MMT in 2006–07. There are infrastructural issues to be addressed also, which will be dealt with in detail in the section on fuel related infrastructure.

Annex 5.7 International experience with CNG

Development of natural gas as an alternative automotive fuel has taken place for many reasons and conditions. In the countries where natural gas has developed as a viable alternative, infrastructure development and abundance of domestic natural gas supply for supply of natural gas have been major factors in the development of natural gas markets. More important than large domestic gas reserves is the availability of a city gas distribution network. Infrastructure for supply of natural gas mainly consists of cross-country pipelines, compressors and gas-dispensing stations.

Some Far Eastern countries have significantly increased use of CNG in vehicles with a significant growth in LNG imports and related infrastructure. In countries such as Japan and South Korea, the major source of natural gas is imports. In this context it is pertinent to note that LNG comprises more than 25% of Japan's energy supply for power production when compared to only 23% of the energy supply from petroleum. This is in striking contrast to many developing countries like India where the major energy source has been petroleum followed by coal and gas comprises a very small source of energy. In these countries the LNG import infrastructure has developed significant over the past two decades with Japan emerging as one of the biggest LNG importers in the world. With domestic natural gas resources depleting and expected to last only till about 2010, imported LNG will be the major source of natural gas and hence will be the determinant of natural gas prices in the long term. Another important inference that can be drawn from the growth of natural gas in various countries is the abundance of domestic sources of natural gas leading to development of the markets, specifically in the case of countries like Argentina,

Venezuela, Egypt etc. Argentina has the greatest penetration of gas-powered vehicles based on rich supplies of natural gas, which account for nearly 50 percent of the country's primary energy. In 2000, there was a network of 11,000 miles of trunk pipelines and 93,000 miles of distribution lines. Filling stations costing one million dollars pay back capital in less than three years, and there are now 774 public filling stations throughout the country (William 2000). Many large cities in Bangladesh, Brazil, Colombia, Indonesia, Pakistan and Eastern Europe and the Former Soviet Union already have extensive gas networks.

It is also to be noted that whilst the initial development of natural gas vehicles was in the passenger car segment, recent growth has been more significant in heavy-duty applications due to the growing concern of particulate matter emissions from diesel engines as has been pointed out earlier. To develop auto CNG markets, education and training programmes, quality control and industry support systems, regulations and equipment standard will have to be included. The varying proportions of methane in natural gas must be taken into account during the processing of the gas, in order to ensure a standard product.

The main barrier to the use of natural gas as a transport fuel is the limited market penetration of vehicles running on it, which in turn is partly due to the lack of a refuelling infrastructure. The implementation of a natural gas transportation system comprising vehicles, fuelling infrastructure and trained personnel depends partly on economic circumstances and the political decision to influence these in a way conducive to natural gas usage.

Annex 5.8 CNG quality

Wobbe Index

In a number of countries, the Wobbe Index (ratio of volumetric heating value to the square root of the specific gravity of the gas) is standardized which ensures that there is some degree of consistency as far as natural gas quality is concerned. The Wobbe Index would provide a useful means to fix the optimum air-fuel ratio in order to achieve best efficiency and power output. In the Indian context automobile companies should work towards standardization of CNG quality by having a specification for the Wobbe Index, which would help in maintaining a particular level of engine performance. This property is also important for fuel metering which is an important aspect of maintaining accurate air-fuel ratios based on the composition of the fuel. Pure methane has a Wobbe Index of 50.61 MJ/m³. The automobile companies should ask for standardization using indices such as the Wobbe Index for the quality of CNG, which currently has no standard other than the minimum pressure requirement.

Molecular composition of CNG

Modern, stoichiometric spark ignition engines with closed loop control of the air-fuel ratios are able to compensate for reasonable variations in the Wobbe Index. For engine control systems without air-fuel ratio feedback, such as those used in heavy-duty engines, variations in fuel composition can present a significant problem—possibly resulting in either poor engine performance (due to too lean a mixture) or engine damage due to overheating (with the mixture too rich).

Methane number

Another parameter, which is used to determine the combustion behaviour of CNG, is the methane number (MN), which is similar to the Octane Number of petrol. Just like iso-octane has an Octane Number of 100 and n-heptane has an Octane Number of 0, pure methane has a Methane Number of 100 and hydrogen has a Methane Number of zero. Studies by the South West Research Institute conclude that the Motor Octane Number (MON) and Methane Number are highly correlated (CONCAWE, 1995).

Typical CNG specifications

There are currently no specifications for CNG sold in Indian cities. Table A5.7 provides a listing of important parameters that need to be standardized in order to ensure low emissions from CNG engines.

Table A5.7 CNG typical specifications

Property and units	Specification	EPA in use CNG	Suggested typical value
Methane content, vol %	Minimum	89	89
Ethane content, vol %	Maximum	4.5	4.5
Wobbe index, btu/scf	Minimum	NA	1350
Wobbe index, mj/m ³	Minimum	NA	50
Methane number	Minimum	NA	95
Inert gases, vol %	Maximum	4.0	4.0

NA – Not available.

The typical values are suggested specifications of CNG based on the fact that CNG should have the maximum possible methane content and ensure that the

air/fuel metering systems function and achieve a high combustion efficiency as per the design.

This will ensure that the performance at test level is observed even during normal operation of vehicles, which is particularly important in the context of heavy-duty applications. This will not be much of an issue after CNG is obtained from imported LNG, which consists of almost 99% methane and has a high and constant Wobbe Index.

Annex 5.9 International experience on Gasohol

Ethanol, both as a neat fuel as well as a blend component came into sharp focus during the Oil Shock of 1973 when Brazil launched a programme called the Proalcool Programme. Another important reason for the growth of ethanol was for reducing the CO and HC emissions from petrol. Ethanol which is an oxygenate ensures better combustion as it provides oxygen within the fuel itself making the mixture a leaner one.

This programme in Brazil was launched with many subsidies to sugarcane growers (www.platts.com, August 5th 2002). Due to this programme, there was a significant increase in the percentage of ethanol used both neat as a fuel as well as in petrol as a blend component. Now, as world's largest ethanol producer, Brazil uses nearly 4 million tonnes of ethanol. Approximately 40% of the cars in Brazil run on 100% ethanol fuel and the other 60% use a 22% ethanol-78% petrol blend. In the late eighties the ethanol consumption remained stagnant due to the withdrawal of the subsidies. The growth of neat ethanol cars is almost flat, as the Brazilian government has withdrawn some of the subsidies that were available with neat ethanol.

Europe

The European Commission published an action plan and two directive proposals in November 2001 to encourage the use of biofuels in the transport sector. The action plan and the two directives are given below:

- Reduce the European Union's (EU) dependence on external oil supply.
- Contribute to EU greenhouse gas emission reduction targets as agreed in the Kyoto Protocol.
- Meet the objective of substituting 20% of diesel and petrol fuels by alternative fuels in the road sector by 2020.

The first directive calls for an establishment of a minimum level of biofuels as a proportion of fuels sold from 2005, starting at 2% and reaching 5.75% of

fuels sold in 2010. It is not clear though whether these directives are indicative or mandatory.

The second directive deals with tax issues, seeking to give EU member states the option of offering tax breaks on pure or blended biofuels used in either heating or motor fuels. But the time frame for introduction of these breaks is not clear.

Bio-diesel has gained ground in Europe more than ethanol unlike Brazil or US where ethanol is the major biofuel.

In addition to the EU issuing certain directives, several countries have individually undertaken many projects to increase the use of biofuels. In May 2002, France and Italy received the European Commission's clearance for biofuel tax breaks. As already stated, Europe's focus has been mainly on bio-diesel rather than ethanol (see Annex 5.10). The total bio-diesel production in Europe was around seven lakh tonnes whereas the total ethanol production was only about two lakh tonnes. (Source: Platts, www.platts.com, 5 August 2002).

Ethanol is not used directly in some EU member countries like France. It is converted into an ether called ethyl tertiary methyl ether (ETBE).

USA

With the implementation of the Energy Policy Act (1992), which was aimed at reducing the dependence on imported petroleum by encouraging use of alternative fuels for certain vehicle fleets (such as federal fleets, state government fleets and private fleets). The act required fleets to buy a certain number of alternative fuel vehicles (AFVs) with every new purchase depending upon whether it was a state, federal or private fleet. Increasing AFV purchases under this Act, along with a phase out of MTBE made a significant impact on the bio fuels market of which ethanol is a major component. This was aimed at increasing the penetration of AFVs, which would also help introduction of new technologies for reducing emissions.

Ethanol derived from grain accounts for almost all of current US bio fuel production. The use of ethanol has been boosted by the ban on MTBE, which is being enforced in all states in US. The Clean Air Act of 1990 mandated the use of oxygenated fuel in areas which had high wintertime carbon monoxide emissions and also to reduce the ground level ozone formation due to the photochemical reaction between some reactive hydrocarbons and NO_x. The blending of ethanol or MTBE provided oxygen in the fuel itself, which helped reduce hydrocarbon emissions. The petrol that was mandated in these areas was called 'reformulated petrol'. The US EPA points out that about 300 MMT of pollution has been eliminated nationwide since the RFG programme has been implemented.

The Energy Policy Act presented before the Senate in June 2002 proposes to remove the oxygenated petrol mandate and introduce a minimum renewable fuel standard for all transport fuels with a roadmap for increasing the use of renewable fuels to three times their current levels of usage. This implies that there would be a significant increase in the percentage of ethanol being blended in petrol.

Another major impetus to the increased use of ethanol in US is the lowering of the dependence on foreign oil. Twenty-four gallons of ethanol is equivalent to one barrel of oil. The Renewable Fuel Association of US points out that tripling ethanol consumption could replace Iraqi imports totally.

The main concerns in increasing the use of ethanol is its price and the subsequent effect on the price of petrol. Currently there is a 54 cent per gallon excise exemption on ethanol, which makes it competitive compared to petrol. The competitiveness of ethanol in the neat and blended form would be difficult without no such fiscal incentives in US.

Asia-Pacific

Platts points out that oil production in the Asia-Pacific will decline in the next 5 - 10 years as key oil fields reach maturity with not many major new finds to replace them. Developing gas markets and high oil prices may hold some incentive for exploration but new oil prospects in the region are dim. Lower production from Asia means that there would be increasing dependence on imports from other regions such as the Middle East, Africa, and Latin America. Biofuels are seen as a substitutes for oil products. The major countries in this region where biofuels play an increasingly important role are Australia, China, Thailand, and India, especially in the use of ethanol to replace significant fossil fuel based energy use and to reduce reliance on oil imports.
(www.platts.com/biofuels, 5 August 2002)

Australia

In Australia a study has been undertaken to determine appropriate standards for ethanol blend fuels, following up on concerns of some vehicle manufacturers about operational and mechanical problems. This is a very important aspect of the use of biofuels. The Australian Government intends to use this study to help decide on options for implementing its election commitment to support increased production of biofuels in Australia. It is aiming to develop a broad strategy to increase the production of both bio-diesel and ethanol to about 350 million litres by 2010. Individual state governments in Australia such as that of

Queensland State have also come out in strong support of developing an ethanol industry in the state to reduce the dependence on fossil fuels and more importantly, create a local demand for sugarcane and grain. This will result in increased farm incomes leading to overall economic growth.

China

China sees ethanol as an opportunity to utilize grain surpluses more efficiently and to also reduce oil exports. China is promoting ethanol-based fuels on a trial basis in five cities in the Central and North-eastern provinces. The move not only cuts domestic petroleum consumption and pollution through fossil fuel use, but also creates a new market for China's surplus grain output. There are plans to promote the use of ethanol-based fuels in big cities in the coming years and there is full political support for this programme with the involvement of key economic departments also.

Thailand

The focus in Thailand also has been on increasing self-reliance and reducing oil imports for meeting energy demands. Many steps have been taken to promote the use of biofuels such as excise tax exemption for ethanol and an income tax waiver for investors for the first eight years and only 50% income tax for the next five years. These incentives have already led to the approval of five projects with a production of eight lakh litres per day. The ethanol is sold as a 10% blend with petrol. The incentives given for ethanol would make ethanol-blended petrol cheaper than standard petrol. Ethanol is produced in Thailand mainly from molasses and cassava. It has surpluses of both these products and if they are used to produce ethanol then the Thai government would save significantly as it otherwise has to support farmers coping with low cassava prices. Thailand also proposes to replace the MTBE that is blended in petrol as an octane boosting additive by ethanol in order to save foreign exchange.

Annex 5.10 International experience with bio-diesel

Europe

The use of bio-diesel in Europe is significantly greater than the use of ethanol unlike other countries where the reverse is true. Several countries have taken their own steps to increase the use of bio-diesel. The EU has allowed Italy to charge excise duties at reduced rates on fuels containing bio-diesel, until June 2004. This proposal applies to mixtures containing 5%–25% bio-diesel.

Germany also decided on a biofuels exception from the national ecotax on energy, which is levied on other fuels thereby encouraging the use of bio-diesel.

France, Germany, Italy, Austria, and Belgium are the top producers of bio-diesel. The German production of bio-diesel is increasing fastest among the countries mentioned and in 2000 it grew by more than 30%.

The only bottleneck in the growth of bio-diesel has been the cost of bio-diesel when compared to conventional diesel. EU estimates the cost of bio-diesel to be almost double the cost of conventional diesel after adding the refinery costs of upgrading diesel. Countries like Germany, Austria, and Sweden use 100% bio-diesel in specific fleets. In France, bio-diesel is blended at 30% in captive fleets and also used in blends of 5% in normal diesel fuel. In Italy, it is blended at 5% in normal diesel fuel.

USA

In US as of September 2001, there were over 100 major vehicle fleets using bio-diesel. Credits were given to fleet owners who used bio-diesel. It is also to be noted that the cost of bio-diesel is higher than regular diesel. There are many initiatives taken by the government to lower the production costs of bio-fuels thereby ensuring lower market prices to boost the demand of bio-diesel.

Many organizations are increasingly using bio-diesel in their fleets. Bio-diesel meets the EPA's phase-wise health effects requirement, under the Clean Air Act of 1990, as its emissions are non-toxic and pose a very low health risk. These health effect requirements are framed to reduce the various unregulated emissions based on their epidemiological effects. Also, the standardization of bio-diesel fuel composition by the American Society of Testing and Materials (ASTM), helps in pushing bio-diesel as an alternative fuel in the US market.

Asia-Pacific

The focus in Asia-Pacific countries has been on ethanol rather than on bio-diesel, with many Asian countries having a significant sugarcane production. Australia is the only country where specific efforts have been put into increase the production of bio-diesel and also reduce the cost of production of bio-diesel. Considerable investments have been made in bio-diesel production facilities. The focus in other countries has been mainly on ethanol-blended petrol only and currently bio-diesel is still at a nascent stage in terms of introduction in the market.

Annex 6.1 Diesel and petrol price breakup in August 2002

Indicative MS and HSD Price build-up Mumbai with current taxes		Ethanol Rs14.3 /l	Ethanol 15.5 Rs/l
	Bharat Stage II HSD*	Bharat Stage II MS	Gasohol 5 %
	Rs/l	Rs/l	Rs/l
CIF Price @ Mumbai	9.04	9.38	9.62
Price including BCD*	10.80	11.72	12.03
Price inclusive of customs duty	10.80	11.70	12.00
Marketing Margin	0.40	0.40	0.40
State Surcharge Maharashtra	0.32	0.30	0.30
Price inclusive of Excise duty @ 32 %	13.40	16.00	16.40
Addl Excise Duty, flat rate	1.00	7.00	6.30
Subtotal Inc Excise	14.38	23.00	22.60
Retail pump Operating charges	0.08	0.08	0.08
Sales tax @ 34 %	4.90	6.20	6.10
Price including Sales Tax	19.40	29.30	28.80
Dealers Commission	0.30	0.30	0.30
Retail Selling Price. Rs/l	19.70	29.60	29.10
% of tax	65%	67%	68%

Without the excise exemption it could result in increase in prices of petrol

*There will be a premium for EURO III and EURO IV diesel and petrol

Annex 6.2 CNG price breakup in August 2002

	CNG import	CNG indigenous
	Rs /kg	Rs /kg
CIF Price @ Mumbai	10.10	8.06
Price including Basic Customs duty @ 5 %	10.61	8.06
Cost of distribution	4.72	4.72
Price of Gas Sold to OMC	15.33	12.78
Excise Duty	2.45	2.04
Subtotal Inc Excise	17.78	14.82
Sales Tax @ 13 %	2.31	1.93
Surcharge @ 10 % of sales tax	0.23	0.19
Turnover Tax @ 1 % of basic price	0.15	0.13
Price inclusive of State taxes	20.47	17.07
Dealers Margin	1.20	1.20
Retail Price	21.67	18.27

CNG indigenous is at 115 % of fuel oil parity which gives the complete thermal parity for natural gas.

Cost of pipeline Transportation will be important for interior locations

Annex 6.3 LPG price breakup in August 2002

LPG price buildup	Rs/tonne
CIF Price	11000
Ocean Freight	1225
Inland Transportation	3800
Local charges	9750
Excise duty	29899
Total	29899
Cost per kg	29.9
Cost per litre	17.0 (density - 0.55- 0.58kg/m ³)

Annex 7.1 Characteristics of diesel particulates

Diesel particulates are a complex, dynamic 'system' comprising carbon soot remnants from the combustion process, ash particles from the lubricating oils, sulphates from the lubrication oil (lubes) and fuels, and unburned hydrocarbons. All regulations have thus far been for the mass emissions of PM₁₀, which means particulate matter below the size range of 10 micrometer, but there is increasing concern over respirable PM of size less than 2.5 (PM_{2.5}) micrometer (Johnson 2001). After the formation of these Diesel particulates undergo mechanisms like nucleation and growth, which affect their size and concentration. The properties of these nano-particles vary with time, temperature, and also with dilution ratios in air. The components of PM are discussed below.

Carbon soot

Particulate matter is generated in the combustion chamber. Fuel composition has a very significant impact on engine out particulate emissions. Components of diesel such as poly aromatic hydrocarbons (PAH) and the bigger molecules in diesel are instrumental in the generation of PM. This has led to standards that recommend reducing the PAH content in diesel and also decreasing the T95 point of diesel.

Sulphates, soluble organic fraction and nanoparticle nucleation and growth

The sulphates in PM are due to the sulphur present in the fuel and also the lubricating oils. With the drastic reduction in the sulphur levels of fuels the sulphate component of the PM has significantly reduced.

The soluble organic fraction (SOF) is formed due to the unburnt fuel and lubricating oil. Some partially volatile compounds also form a part of the SOF of the PM.

Nucleation and growth of the PM depends on many factors namely, time, temperature, and also the soot concentration.

Though current regulations only specify particulate mass emissions on an engine dynamometer, future standards are likely to specify the number and size of particulate matter too, because of their link with health. Many studies are being carried out to study the size range of diesel particulate matter, to relate the size to their health effects and comparing PM emissions with emissions from alternative fuels. These factors will gain importance from the policy view point.

Annex 7.2 Diesel particulate filters

These devices are also referred to as particulate traps and perform the following basic functions in the order given below:

- Collection of PM, usually on a ceramic or other similar filter media.
- Regeneration of filter or burning of soot collected on the filter by various mechanisms.

The regeneration step is the most critical part of the process and a variety of methods can be used for it. Some of the common ones are given below.

- Use of catalyst coated on the filter element to reduce the temperature of combustion of the collected soot particles on the filter.
- Use of a NO_x conversion catalyst upstream of the filter to facilitate oxidation of NO to NO₂, which is adsorbed onto the collected particulate and substantially reduce the temperature required to regenerate the filter.
- Using fuel-borne catalysts to reduce the temperature required for ignition of the accumulated material.
- Using electric heating or combustion of atomized fuel by catalysts to heat the incoming exhaust gas to a temperature sufficient to ignite the fuel.

Precious metal catalysts are normally used for this purpose but they are highly sensitive to sulphur. Sulphur dioxide formed during combustion from sulphur in the fuel and lube oils, are oxidized by these catalysts to sulphates which could lead to an increase in PM emissions and also deactivate the catalysts. Reducing the levels of sulphur in the fuel can help alternate both these problems. The effect of fuel sulphur on the performance of the catalysed diesel particulate filters has been extensively studied (Johnson 2001). This paper clearly establishes the relation between the performances of DPF-based devices, which use NO₂ to burn the PM at low temperatures.

Balance Point Temperature (BPT)

This parameter is most critical to the functioning of the PM filter and will determine its extent of regeneration and efficiency. It is defined as the temperature at which the particulate accumulation on the filter equals the particulate oxidation or burning off, wherein there would be no increase in backpressure. The BPT depends on factors such as flow rate, PM composition, NO_x levels, NO_x/PM ratio, sulphur levels, soot loading rate, etc.

The most crucial aspect of this process is engine backpressure which may result from the accumulation of soot due to improper regeneration. This is a very dangerous situation.

All research is concentrated on reducing the BPT of filter systems to ensure proper regeneration of the filters in conditions that are observed in city driving cycles. Apart from the various fuel and engine related factors which the BPT depends on, the regeneration catalyst formulation can significantly affect the BPT. Oxidising NO_x to NO_2 reduces the Balance Point Temperature requirement. NO_2 is a strong oxidizing agent for soot. As energy efficiency from diesel engines increases with the use of turbochargers, EGR (Full out??) which make use of the exhaust gases' heat and pressure, exhaust temperatures will continuously decrease so proper regenerating temperatures and strategies for low temperature regeneration are very important for the future.

Devices that are currently produced comprise oxidation catalysts, which oxidise NO to NO_2 , and then NO_2 in turn oxidizes the soot particles. Some of the processes which catalyse these reactions are also patented by Johnson Matthey whose Continuously Regenerating Technology has already reached full commercialization level and is widely being used to retrofit heavy-duty diesel engine applications.

These technologies have been patented and are commercialized in the US. The requirement of very low levels of sulphur (less than 50ppms) is a major impediment to the development of these technologies. Technologies which are less sensitive to the level of sulphur in fuel should be the focus of future emission reduction technologies.

The light-off temperatures of the filter regeneration are very important for determining the BPT of the filter and depend upon the regeneration mechanism that is used.

Fuel-borne catalysts for filter regeneration

In view of increasing concern over diesel particulates and tightening legislation to control their emission, much work has been done to develop DPFs and systems to allow them to work reliably. Although a filter will effectively trap solid particles, any material in the vapour phase, such as unburned HCs, may pass through the filter and subsequently condense. The use of a catalytic wash coat, either on the DPF itself or on a separate substrate has been proposed to oxidise these HCs and thus reduce the total material emitted.

The use of fuel borne catalysts to aid the regeneration of trapped material within the DPF is well documented (Vincent et al, 2001; Richards and Rogers,

2002; Richards, Vincent and Cook, 2000; Richards, Terry et al., 2001). Such catalysts will also catalyze the oxidation of any HCs bound up within the particulate. The oxidation of such HC occurs at a lower temperature than that of carbon itself, thus allowing lower temperature regeneration of the DPF. This regeneration technology has been discussed in detail because of the potential of this technology for application with diesel fuel containing even 500ppm of sulphur which is a major constraint for other competing technologies.

A key part of the commercial system is the use of a cerium fuel-borne catalyst to reduce the regeneration temperature of the soot. There are other such additives, which are in the development stage in addition to cerium such as iron/strontium (Fe/Sr) and platinum/cerium (Pt/Ce) blends. Various reviews (Johnson, 2001) have determined the dosages of these additives for achieving proper regeneration. Good regeneration has been achieved even at low levels. 4 ppm of Fe/Sr had successful regeneration during normal driving. It was also observed that there was no deterioration in filter performance. The Pt/Ce blend at very low levels in fuels, 0.25 ppm and 5 ppm, respectively performed well in terms of regeneration performance. A study revealed that a diesel engine running with 368 ppm S fuel showed reduction in PM to the extent of 96%. The comparison between the different technologies in terms of particulate matter reduction is summarized in Table 3.1. (Check??) Fuel economy also improved with these additives as they catalyse combustion, thereby improving the fuel efficiency and reducing engine out emissions.

This field must be developed further as the technology does not require the use of very low sulphur levels in diesel fuel.

Some studies have used FBC with an activated (having small amounts of platinum deposited on the filter) filter with 500 ppm S fuel and the regeneration temperatures were observed to be in the range of 300 – 350° C with a PM reduction efficiency of 80%–90%. (Richards, 1999).

The criteria for choosing a particular FBC are given below
(www.dieselnet.com/papers/9909rhodia, 25 Augst 2002):

- 1 Regeneration temperature is only one criterion: it must be compatible with the range of temperatures that the regeneration assistance strategy can provide without a noticeable deterioration of the fuel economy. The regeneration behaviour must protect the filter from thermal excursions or thermal shocks, and the regeneration must be complete and smooth.
- 2 The concentrated FBC must have a shelf life (in terms of stability) corresponding to at least five years of vehicle usage under rigorous climatic conditions.

- 3 The FBC should not change either the physical or chemical characteristic of the diesel fuel.
- 4 The residues of the FBC should not be deposited on or damage injector nozzles, valves, piston rings, or turbocharger blades. Furthermore, they should remain in solid form and not adhere to the combustion chamber over the whole range of temperatures to which they are exposed.
- 5 The residues of the FBC should not chemically react with the filter material or with the canning components in order to avoid corrosion or any other deterioration of the canned filter. FBC action in the combustion chamber as well as its residues in the filter should not provoke the formation of toxic components in the gaseous phase.

FBC technology will need to be implemented in conjunction with the oil-marketing companies, as they will need to add these additives with the concern being the distribution of this fuel only to those vehicles having filters for PM. Currently the distribution of these FBC's is being done in the same way as lubricating. The cost of a 4–8ppm dosage of the FBC with the fuel before injection is about 1.32 rupees/litre (www.cdti.com, 20 August 2002) and in some cases could cost less than using an ultra low sulphur diesel fuel (less than 50-ppm S diesel) along with a catalysed particulate trap.

To summarize, systems, which have catalysts, are more efficient at removing hydrocarbons and hence achieve better efficiencies of filtration. This is particularly true with the SOF of the PM. But in terms of cost of reducing PM from diesel engines to the automobile, oil-marketing and hence the consumer, the FBC could be a more appropriate technology. This technology should be looked at particularly from the point of view of the medium term reduction in particulate matter until the infrastructure for producing and distributing diesel with very low sulphur levels is available. The filter technology is fairly well established and is already highly commercialized. The critical aspects of the design of the filters are the pore opening and the thermal resistance of the filters due to the high temperatures prevalent.

Exhaust gas recirculation

This is not an after-treatment technology but is a technology which uses the exhaust gases as part of the fuel-air mixture in order to make it more lean and also reduce the temperature of the combustion thereby reducing NO_x emissions. NO_x emissions are reduced at lower combustion temperatures and EGR uses this principle to reduce these emissions. (CONCAWE, 1999c)

NO_x emissions reductions achieved using this technology in some European test cycles are about 30% for both light and heavy-duty applications. Another development in this technology is cooled EGR which achieves about 45% reduction in NO_x emissions in heavy-duty applications.

There are some concerns also with EGR, much as increase in PM emissions, deposit formation in the intake. These problems are being addressed by using the exhaust stream downstream of the diesel particulate filter so that the PM does not go back to the engine and cause problems with the fuel injection systems by forming additional deposits. There are no concerns about any adverse effect on the engine performance.

Annex 7.3 European emission test cycles

R-49 test is a 13-mode steady-state diesel engine test cycle. R-49 is used for certification of heavy-duty highway engines through the Euro II emission standard. The R-49 test is performed on an engine dynamometer operated through a sequence of 13 speed and load conditions. Exhaust emissions measured at each mode are expressed in g/kWh. The final test is a weighted average of the 13 modes.

The ETC cycle has been developed by the FIGE Institute, Aachen, Germany, based on real road cycle measurements of heavy-duty vehicles. The final ETC cycle is a shortened and slightly modified version of the original FIGE proposal. Different driving conditions are represented by three parts of the ETC cycle, including urban, rural, and motorway driving. The duration of the entire cycle is 1800 s. The duration of each part is 600 s.

- Part one represents city driving at a maximum speed of 50 km/h, frequent starts, stops, and idling.
- Part two is rural driving starting with a steep acceleration segment. The average speed is about 72 km/h.
- Part three is motorway driving with an average speed of about 88 km/h.

The FIGE Institute developed the cycle with two variants: as a chassis and an engine dynamometer test. For the purpose of engine certification, the ETC cycle is performed on an engine dynamometer. The details of the test procedure are available at http://www.dieselnet.com/standards/cycles/ce_r49.html.

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